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PROCEEDINGS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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OF

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OF THE

American Institute

OF

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Vol. XXXIV **January, 1915** No. 1

Institute Meeting in New York January 8, 1915

The 303rd meeting of the American Institute of Electrical Engineers will be held on the fifth floor of the Engineering Societies Building, 33 West 39th Street, New York, on Friday, January 8, at 8:15 p.m. The meeting rooms will be opened an hour in advance of the meeting for informal conference of members and guests.

The paper to be presented is entitled *Theoretical Investigation of Electric Transmission Systems under Short-Circuit Conditions*, by I. W. Gross. This paper will be found elsewhere in this issue of the PROCEEDINGS and reprints may be obtained on application to the Secretary.

At the close of the technical session a smoker will be held and light refreshments served in the adjoining room on the fifth floor.

The Engineering Foundation

A noteworthy incident in the history of the profession of engineering in the United States will be the inauguration of The Engineering Foundation on January 27, 1915, in the auditorium of Engineering Societies Building in New York.

The Engineering Foundation is the name given to a fund to be administered "for the advancement of the arts and sciences connected with engineering and the benefit of mankind," the basis of which is the initial gift of a considerable sum by a noted engineer for this purpose. The American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers and the American Institute of Electrical Engineers are to be represented equally in the Administrative Board of The Engineering Foundation, by election by the Board of Trustees of the United Engineering Society, which has been made the custodian of the fund.

All members and friends of the engineering profession are invited to these inaugural ceremonies.

Midwinter Convention, February 17-19, 1915

The regular Midwinter Convention of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, 33 West 39th Street, New York, on February 17, 18 and 19, 1915.

A tentative program has been arranged which includes six technical sessions for which papers on the following subjects have been promised. The following list gives the general subjects but not necessarily the specific titles of these papers:

FEBRUARY 17.

Morning Session.

High-Frequency Testing of Insulators, by E. E. F. Creighton.

Written communications on the same subject by Messrs. A. O. Austin, J. E. Way, and Frank Brookfield.

Afternoon Session.

Carrying Capacity of Cables in the Soil, by L. E. Imlay.

Circuit Breakers, by K. C. Randall.

Comparison of Calculated and Measured Corona Loss Curves, by F. W. Peek, Jr.

A 100,000-Volt Portable Substation, by C. I. Burkholder and N. Stahl.

Evening Session.

This session will be devoted to a discussion on the status of the engineer, in which a number of prominent engineers have promised to take part.

FEBRUARY 18.

Morning Session.

Distortion of Alternating-Current Wave Form Caused by Cyclic Variation in Resistance, by F. Bedell and E. C. Mayer.

Dimmers for Tungsten Lamps, by Alfred Waller.

Searchlights, by C. S. McDowell.

Thursday afternoon will be devoted to visits to the 201st Street Station of the United Electric Light and Power Company, and other places of engineering interest.

The New York Reception Committee is arranging for a social function on Thursday evening, the details of which will be announced in the February PROCEEDINGS.

FEBRUARY 19.

Morning Session.

This session will be devoted to the subject of Electrical Precipitation of Smoke, Dust, etc., and three papers are proposed, the authors of which cannot yet be definitely announced. The first paper will contain a historical sketch of the subject, the second paper will be devoted to the theory, and the third paper to the commercial precipitation of dust, fumes and smoke.

Afternoon Session.

The final session of the convention will be Friday afternoon and the general subject of this meeting will be Motor Applications. Several papers have been promised, the subjects of which cannot as yet be announced.

The complete program giving full details of the convention will be published in the February issue of PROCEEDINGS.

Nominations for Institute Officers for 1915-16

As provided in Section 18 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1915, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1915. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available.

The officers to be elected are: a President and a Treasurer, for the term of one year each, three Vice-Presidents for the term of two years each, and four Managers for the term of three years each.

For the information of members, the full text of Section 18 of the by-laws, governing the proposal of candidates for nomination, is printed below:

"SEC. 18. In addition to the names of the incumbents of office, the Secretary shall publish on 'the form showing offices to be filled at the ensuing annual election in May,' provided for in Article VI, Section 30, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the Institute in writing by January 25 of each year.

"The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to."

Convention and Congress, San Francisco, September, 1915

At the meeting of the Board of Directors of the Institute held December 11, 1914, it was decided, after a long discussion of the advantages and disadvantages of the different dates that had been suggested for the Institute convention in San Francisco in 1915, that the best interests of the Institute, considering its relations with other engineering societies and the International Engineering Congress, require that the San Francisco Convention be held in September, and the following resolutions were adopted:

Resolved, that an Institute convention be held in San Francisco in conjunction with the International Engineering Congress in September, 1915, and that the Annual Convention for 1915 be held in the East at the usual time. (Latter part of June).

Resolved, that the San Francisco meeting be officially known as the Panama-Pacific Convention of the American Institute of Electrical Engineers, and that this convention be held during the week beginning September 13, 1915.

Resolved, that the President be authorized to appoint the necessary Panama-Pacific Convention committees to make all necessary arrangements and carry the convention to a successful conclusion.

It was originally intended that the Institute should convene in San Francisco in September, 1915, in conjunction with the International Electrical Congress, which the Institute had undertaken to organize under the authority of the International Electrotechnical Commission. The Commission had also planned a meeting in San Francisco in connection with the Congress.

The plans for the Congress had progressed to a great extent at the outbreak of the European war, but it then became evident to the Executive Committee of the Committee on Organization of the Congress that it would be advisable to postpone the Congress, owing to the improbability of obtaining sufficient international representation to result in a Congress that would be really international in scope, and to the fact that it would be impossible to convene the International Electrotechnical Commission, which is a body composed of national committees in the principal countries throughout the world. The Institute's authority for organizing the Congress had been obtained from the Commission at the meeting held in Turin, Italy, in 1911, but as it was not possible to obtain any official action of the Commission after the outbreak of the war, the Executive Committee of the Committee on Organization of the Congress recommended that the Board of Directors of the Institute adopt resolutions indefinitely postponing the Congress, until such time as in the opinion of the Institute it would be desirable to take steps to organize the next International Electrical Congress in the United States. This action was taken by the Board of Directors at its October meeting and, since then, the money paid in by subscribers to the Congress has been refunded in full.

The International Engineering Congress, dealing with all branches of engineering, is being organized under the auspices of five national engineering societies; namely, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the Society of Naval Architects and Marine Engineers, and the American Institute of Electrical Engineers, all of which are represented upon its Committee of Management. This Congress is to be held during the week beginning September 20, 1915. The advisability of holding this Congress in view of the European war, was considered by the Committee of Management, which strongly recommended that the plans be carried out, and this recommendation was concurred in during October, 1914, by the governing bodies of the five participating societies.

The National Electric Light Association is to meet in San Francisco June 8-11, 1915, and attention has been called to the advantages of holding our Annual Convention in San Francisco at approximately the same time, thus making possible joint transportation and other arrangements, which would be convenient for the members of both organizations.

The Constitution of the Institute requires that the Annual Convention shall be held each year prior to August 1 and, therefore, if the San Francisco Convention were held in September, it could not be designated as the " Annual Convention" for 1915. There is nothing, however, in the Constitution to prevent a special convention being authorized in addition to the Annual Convention.

All of the above facts were considered by the Board of Directors on December 11, and it was felt that if the Institute should hold its Annual Convention in San Francisco in June, no considerable number of Institute members, such as may be expected to attend an Institute convention in San Francisco and to visit the Exposition, would go to San Francisco a second time in September to attend the International Engineering Congress, with the result that there would be a very limited Institute representation at the Congress. This, it was thought, might possibly be construed by the other societies as indifference on the part of the Institute towards the success of the Congress, and might even have a tendency to impair future relations between the Institute and some of the other participating societies.

Furthermore, the Institute's obligations as joint host with the other engineering societies, to the foreign engineers who attend the engineering congress, require that the Institute's San Francisco convention be held in conjunction with the Congress in September. It developed at the meeting of December 11, that the American Society of Civil Engineers has already decided to hold its Annual Convention in San Francisco during the week preceding the Congress; that the American Institute of Mining Engineers will hold its summer convention in conjunction with the Congress; and that the American Society of Mechanical Engineers is considering a special meeting at the same time. It thus appeared evident that there will be a general gathering of engineers in San Francisco in September, not only to attend the meeting of the International Engineering Congress, but also to attend the various conventions of the national engineering societies as outlined above.

In view of all these facts, particularly with reference to the Institute's friendly relations with, and obligations to, the other societies, and our moral responsibility to cooperate with them for the success of the Congress, the Board decided to hold the Panama-Pacific Convention of the Institute in San Francisco during the week beginning September 13, which is the week originally set for the meeting of the Institute and the International Electrical Congress.

The Work of the Standards Committee and Its Capability for Usefulness to the Institute Members

The work of the Standards Committee of the A. I. E. E. is of great value to the profession and to every user of electrical power. This work would not be possible without the American Institute of Electrical Engineers or a similar organization; it is a very convincing argument why every electrical engineer should support the Institute by joining. Dr. Kennelly has been chairman of the Standards Committee for the past several years and the following article by him sets forth the work of the committee in a very clear manner.

H. D. JAMES,
Chairman, Membership Committee.

The American Institute of Electrical Engineers maintains, among its standing committees, a "Standards Committee," which is charged with the important duty of maintaining a series of Standardization Rules for the benefit of the Institute and its members.

Brief Historical Outline. The Institute in 1891[1] appointed a standing committee on "Units and Standards" which was maintained until 1900, and which prepared, among other reports, a Table of Standard Copper Wire Resistances in 1893.[2] In 1898[3] a new standing "Committee on Standardization" was appointed, which, renewed from year to year, has continued to the present time. Its first report was presented and accepted in June, 1899,[4] covering 14 pages of rules for dynamo-electric machinery. This first edition of Rules was replaced by a second edition adopted in June, 1902,[5] covering 18 pages. The third edition, of 32 pages, was adopted in June, 1907,[6] at which time the title of the committee was changed in the constitution to the "Standards Committee." A fourth edition of the Rules, with 36 pages, was presented and adopted by the Board of Directors in June, 1911.[7] The fifth and most recent edition, dated December 1, 1914, was adopted by the Board in July, 1914. It covers 96 pages.

Object of the Rules. The main purpose hitherto aimed at by the Standards Committee in the rules has been to draw up engineering definitions of terms, phrases, and requirements, relating to electrical machinery and apparatus, so that the meaning of technical terms might be standardized among the members of the Institute. Particular effort has been directed towards defining, in engineering terms, the rating of electrical machinery, and the requirements connoted thereby. Although, primarily, the object of the Committee is to assist the membership of the Institute in arriving at a precise understanding of the technical terms used in electrical engineering, especially as applied to characterising the behavior and properties of machinery, yet, in so far as the committee is able thus to serve the membership, it also necessarily serves the entire electrical industry, including manufacturers, purchasers, technical advisers, operators, and consumers. It is therefore desirable that the representation of electrical interests on the Standards Committee should be as wide as possible, in order that the needs of all classes of electrical workers should be adequately presented and mutually protected.

The Standards Committee, like other standing committees, terminates its existence at the end of each Institute administration year, and is renewed through direct annual appointment by the incoming President and Board. The personnel of the committee thus changes from year to year. It has, however, hitherto been the practise of the Institute to retain a sufficient number of members from each preceding committee to ensure continuity of procedure in the committee work.

Relations of the Standards Committee to other Engineering Bodies. The work of the Standards Committee naturally brings the committee into contact with bodies engaged upon standardization in neighboring fields. Thus, it has for a number of years cooperated with the Bureau of Standards at Washington, D. C. The Bureau has not only been continuously represented by one or more of its officers on the Committee, but it has also undertaken important researches in electrical engineering at the request of the Committee. Thus, in 1910, the Bureau, at the request of committee, made an extensive investigation into the conductivity of commercial copper and has since published complete copper wire tables[8] based on those researches, for the benefit of the electrical industry.

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[1] Institute Secretary's Report, May 1891. Vol. VIII.

[2] A. I. E. E. TRANS., Oct. 1893, Supplement, Vol. X.

[3] A. I. E. E. TRANS. Jan. 1898, Vol. XV, p. 22.

[4] A. I. E. E. TRANS., June 1899, Vol. XVI, pp. 255-268.

[5] A. I. E. E. TRANS., June 1902, Vol. XIX, pp. 1074-1091.

[6] A. I. E. E. TRANS., June 1907, Vol. XXVI, part 2, pp. 1795-1825.

[7] A. I. E. E. TRANS., June 1911, Vol. XXX, part 2, pp. 1923-1955.

The A. I. E. E. Standards Committee has also at different times worked in cooperation with Standards Committees of the American Society of Mechanical Engineers, the Illuminating Engineering Society, the Institute of Radio Engineers, the American Society for Testing Materials, the National Electric Light Association, the Association of Edison Illuminating Companies, and other bodies, upon questions of standardization involving work in their respective fields. It has been the policy of the Committee, under specific instructions from the Board of Directors, not to standardize in a field overlapping the interests of another technical society, without consulting that society with a view to joint cooperative action. It seems likely that such mutual cooperation between the various American engineering societies may become more necessary and extensive as time goes on. Judging from experience in the past, it may be hoped that each engineering society will maintain its own standards committee in such a manner that joint meetings may be readily possible, for joint purposes, subject to the control and authority of the respective governing boards. In this way, a standards committee representing the entire engineering force of America may ultimately be secured for dealing with general engineering questions.

International Standardization. The conditions which affect the mutual relations of different engineering societies in America regarding standardization, naturally extend themselves internationally between corresponding engineering societies in other countries. It becomes impossible to carry standardization beyond a very elementary stage in any one country, without influencing the work and procedure along similar technical lines in other countries. It therefore becomes desirable to enter into mutually cooperative relations with electrical engineering societies and their standardizing committees abroad. Cooperative relations have been entered into at different times between the A. I. E. E. Standards Committee and corresponding committees in other countries, to considerable mutual advantage; but especially through the influence of the International Electrotechnical Commission, an international body engaged in international electrical engineering standardization. The American Standards Committee of the A. I. E. E. was the first national committee to formulate and publish electrical standardization rules, and similar committees have since come into existence in various other countries. If it is recognized as desirable to define electrotechnical terms, phrases, and machine properties for one country, it becomes all the more necessary to bring the various national definitions and sets of rules into accord. It is neither necessary nor desirable that electrical apparatus built in one country should conform in structural details to that built in other countries; but it is surely desirable that the rating, and rating terms, employed in specifying the behavior of apparatus in different countries should correspond, since no country can permanently profit by ambiguity, in the meaning of its technical phraseology, as applied to the physical behavior of apparatus.

The Standards Committee of the A. I. E. E. has no direct representation on the International Electrotechnical Commission (I. E. C.); but it has close relations with the U. S. National Committee of the I. E. C., and, through the intervention of the latter committee, it has been able to present its needs and recommendations to the I. E. C. Various rulings of the I. E. C. at past international meetings are now incorporated in the latest edition of the Rules.

The Relations of the Standards Committee to the Institute Membership. The work of its Standards Committee constitutes a distinct asset to the Institute, and to the membership. The committee meetings usually occur at monthly intervals in the New York headquarters of the Institute, and are well attended, various members frequently coming from cities as remote as Chicago, Boston, Washington, Pittsburgh, etc., in order to attend them. Notices of these meetings are communicated in advance to the Standards Committees of other engineering societies, and are regularly announced at headquarters. It has been the policy of the Committee to welcome representatives of any engineering society, Section of the Institute, or of the A. I. E. E. membership generally; so that any member interested in the work has been free to attend the meetings, and to obtain a hearing, by request, upon any matter of sufficient importance to occupy the committee's time. Moreover, frequent notices to the members have been issued from the A. I. E. E. Secretary's office inviting suggested extensions or amendments of the Rules. A considerable number of such suggestions regularly reach either the A. I. E. E. Secretary, or the Secretary of the Committee, and these receive careful consideration by the Committee. It is very desirable to secure frequent and copious suggestions, from the Institute membership at large, as to how the Rules operate in practise, and how they may be improved.

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[8] Circular No. 31 of the Bureau of Standards, "Copper Wire Tables".

In recent years it has been necessary to divide the work of the Committee by the appointment of sub-committees on special branches of the work. These sub-committees meet independently, and more frequently than the main committee, enlisting the aid and attendance of Institute members not actually appointed on the Standards Committee. In this way, information and guidance has been sought and secured in special fields. No one member of the main committee can be expected to be familiar with all of the branches of the Committee's work.

The Standards Committee is thus a body earnestly devoting its time and service to the welfare of the Institute membership and of the electrical engineering industry, in the belief that precision in standardization means an advance in the ethics, the science, the business and the welfare of engineering. It is hoped that the membership will cooperate with the Committee towards making the Rules meet their purpose.

A. E. KENNELLY,
Chairman, Standards Committee.

Directors' Meeting, New York, December 11, 1914

The Board of Directors of the Institute held its regular monthly meeting at Institute headquarters in New York, on Friday, December 11, 1914, at 3:30 p.m.

There were present: President Paul M. Lincoln, Pittsburgh, Pa.; Past-Presidents Ralph D. Mershon and C. O. Mailloux, New York; Vice-Presidents H. H. Barnes, Jr., Charles E. Scribner, New York, F. S. Hunting, Fort Wayne, Ind., Farley Osgood, Newark, N. J.; Managers C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William B. Jackson and P. Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y., William McClellan, Bancroft Gherardi and A. S. McAllister, New York, John H. Finney, Washington, D. C.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $11,312.89 was ratified.

Upon the petition of Professor Gustav Wittig, and the approval of the Sections Committee, the organization of a Branch at the University of Alabama, Tuscaloosa, Ala., was authorized.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred five Associates to the grade of Member, elected two applicants as Members and 47 as Associates, and ordered the enrolment of 171 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

In response to an invitation from the chairman of the Public Lands Committee of the United States Senate, the President was authorized to appoint a special committee to appear at hearings upon the Ferris bill relating to the development of water power, this being in accordance with the action taken last spring when the Institute was represented by a similar committee at hearings upon the same bill before the House Committee on Public Lands.

A communication from the American Association for the Adoption of the Metric System, soliciting the Institute's co-operation, was referred to the Standards Committee.

The President was authorized to appoint a Constitutional Revision Committee to report at the next meeting whether in its opinion any revision of the constitution is desirable at the next annual meeting.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

Research Fellowships at the University of Illinois

To extend and strengthen the field of its graduate work in engineering, the University of Illinois has since 1907 maintained ten Research Fellowships in the Engineering Experiment Station. These fellowships, for each of which there is an annual stipend of $500, are open to graduates of approved American and foreign universities and technical schools. Appointments to these fellowships are made and must be accepted for two consecutive collegiate years, at the expiration of which period, if all the requirements have been met, the Master's degree will be granted. Not more than half of the time of the Research Fellows is required in connection with the work of the department to which they are assigned, the remainder of the time being available for graduate study.

Nominations to fellowships, accompanied by assignments to special departments of the Engineering Experiment Station, are made from applications received by the Director of the Station each year not later than the first day of February. These nominations are made within the month of February by the Station Staff, subject to the approval of the Faculty of the Graduate School and the President of the University. Appointments are made in March, and they take effect the first day of the following September. Vacancies may be filled by similar nominations and appointments at other times.

Nominations to these fellowships are based upon the character, scholastic attainments, and promise of success in the principal line of study or research to which the candidate proposes to devote himself. Preference is given those applicants who have had some practical engineering experience following their undergraduate work.

The Engineering Experiment Station, an organization within the College of Engineering, was established in 1903 for the purpose of carrying on investigations in the various branches of engineering, and for the study of problems of importance to engineers and to the manufacturing and industrial interests of the State. Research work may be undertaken in architecture, architectural engineering, chemistry, civil engineering, electrical engineering, mechanical engineering, mining engineering, municipal and sanitary engineering, physics, railway engineering, and in theoretical and applied mechanics.

The work of the Station is closely related to that of the College of Engineering, and the heads of departments in the college constitute the administrative station staff. Investigations are carried on by the members of the staff and other members of the instructional force of the College of Engineering, by special investigators employed by the Station, and by the Research Fellows.

Annual Barbecue of Atlanta Technical Societies

The second annual barbecue of the Affiliated Technical Societies of Atlanta, Ga., was celebrated on September 19, 1914, in the grounds of the City Pumping Station, with some eighty technica men in attendance, members of the local sections of the following organizations: American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Chemical Society, American Institute of Architects, and the Engineering Association of the South.

During the course of an old-fashioned Georgia barbecue with all the " trimmings", the meeting was called to order by Mr. A. M. Schoen, chairman of the executive committee of the Affiliation, who spoke briefly on the object of the meeting and the purpose of the organization. Several other short addresses were made on topics connected with engineering and the relations of engineers to public affairs.

Past Institute Meetings

New York.—The 302d meeting of the Institute was held Friday, December 11, 1914, on the fifth floor of the Engineering Societies Building, beginning at 8:20 p.m. President Paul M. Lincoln presided.

Mr. F. W. Peek, Jr., presented his paper on *The Effect of Altitude on the Spark-Over Voltages of Bushings, Leads and Insulators,* and was followed by Mr. A. O. Austin, who presented his paper entitled *Insulator Depreciation and Effect on Operation,* The two papers were discussed together by Messrs. H. L. Curtis, D. B. Rushmore, E. D. Eby, P. W. Sothman, Selby Haar, Charles P. Steinmetz, Farley Osgood, F. W. Peek, Jr., and A. O. Austin.

At the close of the technical session, a smoker was held in the adjoining room.

Past Section Meetings

Boston.—November 18, 1914, Chipman Hall. Address by Mr. Henry M. . Waite on " The Commission-Manager Form of Government and Its Relation to the Engineering Profession." Joint meeting with Civil and Mechanical Engineers. Attendance 350.

Cleveland.—November 18, 1914, Municipal Lighting Plant. Inspection trip to municipal lighting plant, and address by Mr. F. W. Ballard on engineering features of the plant. Attendance 82.

November 23, 1914, Chamber of Commerce. Subject: Telephony. Paper: " The Automatic Telephone—Its Operation and Construction," by Mr. Arthur Bessey Smith. Attendance 57.

Detroit-Ann Arbor.—November 27, 1914, Detroit Engineering Society rooms. Illustrated paper by Mr. F. A. Fishback on " Some Motor Control Problems." Attendance 52.

December 4, 1914, Detroit Engineering Society rooms. Subject: Illumination. Paper: "Importance of Direction, Quality and Distribution of Light," by Mr. M. Luckiesh, illustrated by lantern slides.

Fort Wayne.—November 19, 1914, Commercial Club. Address by Mr. E. A. Barnes on " Factory Problems." Attendance 9.

Los Angeles.—November 17, 1914, Chamber of Commerce. Discussion on Report by the Joint Committee on Inductive Interference to the Railroad Commission of the State of California. Attendance 68.

December 8, 1914, Chamber of Commerce. Subject: Storage Batteries. Papers: (1) " Lead Storage Batteries." by Mr. J. A. Solomon, (2) " Edison Storage Batteries," by Mr. J. F. Rogan. Attendance 64.

Lynn.—November 18, 1914, West Lynn. Address by Mr. D. A. Capen on " The Manufacture of Crucible Steel." Attendance 248.

December 2, 1914, West Lynn. Lecture by Prof. Elihu Thomson on " Wireless Telegraphy." The lecture was illustrated by numerous lantern diagrams. Attendance 372.

Minnesota.—November 23, 1914, Main Engineering Building, University of Minnesota. Address by Mr. R. R. Price on the work of the university in bringing its facilities to people who cannot come to it. Short talk by Prof. Shepardson on technical training. Joint meeting with Jovian League. Attendance 100.

Pittsburgh.—October 21, 1914, Oliver Building. Subject: Electric Welding. Paper: " Electric Welding—Kinds and Applications," by Mr. C. B. Auel. Paper illustrated by lantern slides and samples. Attendance 115.

November 10, 1914, Oliver Building. Paper: " The Distribution System of a Large Central Station," by Mr. E. C. Stone. Paper illustrated by lantern slides and motion pictures, explained by Mr. D. C. Black. Attendance 101.

Pittsfield.—November 19, 1914, Hotel Wendell. Paper: " The Mercury Vapor Turbine," by Mr. W. L. R. Emmet, illustrated by lantern slides. Attendance 85.

Portland.—November 10, 1914. Subject: " Telephony. Paper: " A Telephone Plant with Relation to Fires," by Messrs. W. D. Scott and G. P. Nock. Also illustrated address on " Progress in Telephone Plant Construction," by Mr. W. D. Scott, and inspection trip to Pacific Telephone and Telegraph Company's new exchange building. Joint meeting with local section of N. E. L. A. Attendance 70.

December 1, 1914. Paper: " A Hydroelectric Development in Spain," by Mr. John C. Stevens. Attendance 50.

Rochester.—November 27, 1914. Paper: " Illumination," by Mr. F. C. Taylor. Attendance 50.

San Francisco.—November 20, 1914, Engineers Club. Symposium on " Sporadic Insulator Troubles;" short papers by Messrs. P. M. Downing, Harris J. Ryan, J. E. Woodbridge and J. P. Jollyman. Attendance 83.

Schenectady.—December 1 and 2, 1914, All Souls Church. Illustrated address by Mr. John B. Taylor on " Electrical Musical Instruments." Inspection of Choralcelo recently installed in the church. Total attendance 235.

December 15, 1914, Edison Club Hall. Subject: Abnormal Luminous Manifestations. Papers: (1) " Lighting and Corona," by Mr. E. E. F. Creighton, and (2) " Phosphorescence and Fluorescence," by Mr. W. S. Andrews. Both papers were illustrated by experimental demonstrations. Attendance 116.

Seattle.—November 17, 1914, Central Building. Paper: " Repulsion Induction Motor," by Mr. W. M. Strickler. Short talks by Messrs. A. A. Miller, J. D. Ross, M. T. Crawford, J. R. King, J. F. Curtiss and E. A. Loew on " The Breaking-in Period of the Engineering Graduate." Attendance 51.

St. Louis.—November 11, 1914, Engineers Club. Paper: " Some Practical Applications of the Principles of Statistics," by Mr. Charles S. Ruffner, illustrated by lantern slides. Attendance 53.

Toledo.—December 2, 1914, Toledo Commerce Club. Paper: " Electric Charging Apparatus for the Private Garage,,' by Mr. J. F. Lincoln. Attendance 19.

Urbana.—November 20, 1914, Electrical Engineering Laboratory. Paper: " Theories of Valuation as Developed by the New Public Utilities Commission," by Mr. R. E. Heilman. Attendance 32.

Washington.—November 17, 1914, Bureau of Engraving and Printing, New Building. Inspection of electrical installation in the new building for the Bureau of Engraving and Printing, including description of the interesting features by Mr. E. C. Stanton. Attendance 65.

Past Branch Meetings

University of Cincinnati.—November 19, 1914, Engineering College. Paper: "A Meterman's Troubles," by F. H. Obserschmidt. Attendance 40.

December 3, 1914. Paper: "Electricity Commercialized," by A. A. Campbell. Attendance 55.

University of Colorado.—November 12, 1914, Boulder, Colo. Address by Mr. E. L. Siekmann on "Electrical Merchandising." Attendance 43.

December 10, 1914, Boulder, Colo. Address by Mr. A. W. Hahn on "Organization and Management." Attendance 38.

Colorado State College.—November 20, 1914, Electrical Building. Discussion of the Standardization Rules of the A. I. E. E. by Professor Rankin. Attendance 12.

Iowa State College.—November 17, 1914, Ames, Iowa. Moving pictures showing the manufacture of small induction motors by the General Electric Company. Prof. F. D. Paine explained the various processes. Attendance 51.

University of Kentucky.—November 25, 1914, Mechanical Hall. Paper: "Development of Power at Niagara Falls," by N. E. Philpot. Attendance 27.

December 9, Mechanical Hall. Paper: "Railway Motors and Control," by M. W. Arthur. Attendance 36.

Lafayette College.—December 2, 1914, Pardee Hall. Papers: (1) "Edison Storage Battery, (2) "Gasoline-Electric Car," and (3) "Electrical Ignition for Gasoline Motor Cars." Attendance 21.

December 9, 1914, Pardee Hall. Papers: (1) "Tesla or High-Frequency Currents," (2) "The Present and Future of the Gas Turbine," and (3) "The New Generators at Station A1 in Philadelphia." Attendance 21.

December 16, 1914, Pardee Hall. Papers: (1) "Insulator Depreciation and Effect on Transmission," (2) "The Cost of a Kilowatt-Hour," and (3) "Direct - Current Corona". Attendance 21.

University of Maine.—November 6, 1914, Lord Hall. Election of officers as follows: chairman, H. H. Beverage; vice-chairman, H. W. Coffin; secretary, W. E. Bowler; Treasurer, M. R. McKenney. Attendance 17.

November 6, 1914, Hannibal Hall. Address by Mr. E. J. Wilson on "The Student Electrical Engineer and His Problems." Attendance 30.

University of Missouri.—November 24, 1914, Engineering Building. Paper: "Electric Cooking," by P. W. Gumaer. Attendance 21.

December 8, 1914, Engineering Building. Paper: "Electricity on the Farm," by O. R. Allgeier. Attendance 15.

University of North Carolina.—October 28, 1914, Chapel Hill. Election of officers as follows: chairman, P. H. Daggett; secretary, J. W. McIver. Attendance 30.

November 13, 1914, Chapel Hill. Papers: (1) "The Education of the Electrical Engineer," by P. H. Daggett, (2) "Electrical Equipment of a Modern Battleship." Attendance 30.

December 11, 1914, Chapel Hill. Papers: (1) "Development of the Mazda Lamp," (2) "The Corona in Direct-Current Circuits." Attendance 25.

North Carolina Agricultural and Mechanical College.—November 17, 1914, West Raleigh. Illustrated addresses by Messrs. D. G. McArn, A. C. Fluck, D. H. Hill, and G. M. Carter. Attendance 36.

December 8, West Raleigh. Experimental demonstration of the effects of the physical constants of electric circuits given by Mr. H. M. Alexander. Attendance 33.

Ohio Northern University.—November 18, 1914, Hill Memorial. Address on "Conductivity Test" by Mr. Kitaif, and "Homopolar Machines," by Prof. E. B. Thurston. Attendance 23.

University of Oklahoma.—October 21, 1914, Norman. Papers: "The A. I. E. E. and Its Work," by H. V.

Bozell, and "Transformer Construction," by L. W. W. Morrow. Election of officers as follows: chairman, Clarence Karcher; vice-chairman, Homer Livergood; secretary, W. M. Vernor; treasurer, Randal Clark. Attendance 9.

November 18, 1914, Norman. Papers: "Men Who Made the Electrical Engineer Possible," by Clarence Karcher, and "2400-volt Electric Railroad," by M. C. Oakes. Attendance 14.

Rensselaer Polytechnic Institute.—November 23, 1914, Sage Laboratory. Paper: "Construction and Application of the Oscillograph," by F. M. Sebast Attendance 37.

Rose Polytechnic Institute.—December 8, 1914. Address by Mr. Dunn on "Automatic Telephones." Attendance 15.

University of Texas.—November 19, 1914. Election of officers as follows; chairman, J. M. Bryant; secretary and treasurer, J. A. Carrell. Attendance 8.

Agricultural and Mechanical College of Texas.—November 20, 1914, Electrical Engineering Building. Papers: "Brushes," by A. Dickie, and "Submarine Signaling," by E. N. Hogue. Attendance 40.

Washington University.—November 2, 1914, St. Louis. Illustrated lecture on "The Industrial Safety-First Movement." Joint meeting with A. S. M. E. Branch. Attendance 52.

University of Washington.—December 8, 1914, Good Roads Building, Seattle. Papers: (1) "Development of Railway Signal Practise," by S. J. Turreff, and (2) "Distribution of Electric Power," by M. T. Crawford. Attendance 35.

Worcester Polytechnic Institute.—December 11, 1914. Paper: "Engineering and Politics in a City of the First Class," by Leonard Day. Attendance 60.

Yale University.—November 12, 1914, New Haven. Paper: "Electricity in the Navy," by C. S. McDowell. Attendance 95.

Personal

MR. JOHN FRANCIS WARREN was recently appointed by the Borough Council of Napier, New Zealand, to the position of Civil and Electrical Engineer to the Borough.

MR. C. W. COLVIN has been appointed Transmission Engineer of the British Columbia Electric Railway Company, and is now in charge of the high-tension lines and telephone system of the company.

MR. W. N. SMITH, having completed his work as consulting engineer to the San Francisco-Oakland Terminal Railways of Oakland, California, has returned East. His address for the present is 205 Ten Eyck Street, Watertown, N. Y.

MR. DANIEL W. MEAD, consulting engineer, of Madison, Wis., who has been away from the United States during the past summer as a member of the American National Red Cross Board of Engineers, Chinese River Conservancy, has returned and is prepared to make examinations, reports, plans and specifications for water power, water supply, flood protection, drainage, irrigation, power plants and power transmission installations.

MR. RODOLFO ROTH, a consulting engineer of Buenos Aires and Professor at the National University of La Plata, is at present visiting this country, with headquarters at 100 West 80th Street, New York City. Mr. Roth is a graduate of Cornell University and has in the past been superintending engineer for the Cia. de Iluminacion y Ornato of Buenos Aires, 1st assistant to the manager of the Buenos Aires branch of the General Electric Company, and later manager of the machinery department of Buxton, Cassini and Company of the same city. Mr. Roth is familiar with trade conditions in Argentina, and will be glad to meet American manufacturers seeking information on the subject.

Obituary

CHARLES E. HANSELL, assistant manager of the Esterline Company, of Indianapolis, Ind., died on November 25, 1914, as the result of injuries received in an automobile accident on the afternoon of the day before. Mr. Hansell was on his way home from his office when his automobile was struck by a street car. Mr. Hansell was born in Medaryville, Ind., 31 years ago. He was graduated from the electrical engineering department of Purdue University in 1907, and shortly afterward entered the employ of the Western Electric Company at Chicago. Later he was electrical engineer of the Duncan Electric Company, La Fayette, Ind., and three years ago became connected with the Esterline Company, then at La Fayette, as assistant manager and instrument engineer. He was recognized as an authority on electrical instruments and meters. Mr. Hansell was elected an Associate of the Institute on November 10, 1911, and was transferred to the grade of Member on February 14, 1913.

JOSEPH EDWARD PUTNAM, of Rochester, N. Y., assistant City Engineer, in charge of City Engineer's Testing Laboratory, died on December 9, 1914, at the age of 54. He was born in Rochester, and educated in the public schools of that city. After several years of experience with the Western Electric Company in New York, the Central Union Telephone Company in Indiana and Illinois, and the Postal Telegraph Company in La Porte, Ind., Mr. Putnam taught for one year in physics at the University of Michigan. Afterward he was a contractor and later consulting electrical engineer in Rochester, prior to beginning his work for the city. Mr. Putnam was elected an Associate March 27, 1903. A son, Joseph Franklin Putnam, also an Associate of the Institute, is head of the department of physics in St. Johns University, Shanghai, China.

Transferred to the Grade of Member December 11, 1914

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on December 11, 1914.

ATKINSON, RALPH WALDO, Asst. to Chief Engineer, Standard Underground Cable Co., Perth Amboy, N. J.

HATCH, EDWIN GLENTWORTH, Electrical and Mechanical Engineer, New York, N. Y.

JONES, EDWARD CROSBY, Electrical Engineer, c/o Crocker-Wheeler Co., Ampere, N. J.

MIDDLETON, W. IRVING, Electrical Engineer, Testing Dept., Simplex Wire & Cable Co., Cambridge, Mass.

MITCHELL, GUY K., Proprietor, Standard Electric & Elevator Co., Baltimore, Md.

Members Elected December 11, 1914

CLEWELL, C. E., Asst. Prof. Elec. Engg., University of Pennsylvania; res., 4919 Osage Ave., Philadelphia, Pa.

THOMSON, ROBERT DOUGLAS, Asst. Professor of Electrical Engineering, University of Vermont, Burlington, Vt.

Associates Elected December 11, 1914

AYYA, D. VISVANATH, Shift Engineer, Power Station, Electricity Department, Hyderabad, Deccan, India.

BAHM, JOHN F., Construction Foreman, Construction Dept., General Electric Co., Schenectady, N. Y.

BEASLEY, THOMAS E., Assistant Sales Manager, American Engine and Electric Co., Bound Brook, N. J.

BUCKLEY, J. V., Testman, General Electric Co.; res., 108 Park Place, Schenectady, N. Y.

Capen, William Henry, Western Electric Co.; res., 604 23rd St. Y. M. C. A., New York, N. Y.

Cottle, George T., President, A. A. Wire Co., Inc., 48 Nesbitt St., Newark, N. J.

Crabtree, Arden D., Operating Dept., Lock 12 Hydro-Electric Plant, Alabama Power Co., Clanton, Ala.

Craig, C. W., Jr., Chief Clerk, Philadelphia Repair Dept., General Electric Co.; res., 902 N. Fallon St., Philadelphia, Pa.

Cram,' W. C., Jr., Superintendent of Construction, Alabama Power Co., Birmingham, Ala.; res., Raleigh, N.C.

Dixon, Amos F., Executive head of Telegraph Development Branch, Western Electric Co., New York, N. Y.; res., 327 N. 7th St., Newark, N. J.

Edgar, Grant E., Assistant Electrical Engineer, Electric Boat Co., Groton; res., 16 Nathan Hale St., New London, Conn.

Eldredge, Mark, Deputy Chief Engr., Tata Hydro-Elec. P. S. Co. Ltd.; res., A16 Mt. Pleasant Rd., Malabar Hill, Bombay, India.

***Felton, John G.**, Engineer, Fulton County Gas & Electric Co.; res., 107 Third Ave., Gloversville, N. Y.

Field, Frank E., Instructor in Electrical Engineering, Pennsylvania State College, State College, Pa.

Flaccus, George W., Student, University of Pittsburgh; res., 208 S. Negley Ave., Pittsburgh, Pa.

***Freund, Otto Albert**, Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

***Gibson, A. D.**, Local Manager, Central Iowa Light & Power Co., Rockwell City, Iowa.

Griswold, Samuel A., Engineering Salesman, Hart Mfg. Co., Hartford; res., 63 Hartford Ave., Wetherfield, Conn.

***Heintze, Emil C.**, Electrical Rate Clerk, City Lighting Dept.; res., 343 W. 76th St., Seattle, Wash.

Hering, C. P., Consulting Elec. Engr., Board of Public Utility Commissioners, Manila, P. I.

Hersom, Fred C., Electrical Engineering Dept., C. H. Tenney & Co., 201 Devonshire St., Boston, Mass.

Huang, S. V., Student, Engr., Testing Dept., General Elec. Co., res., 27 Barrett St., Schenectady, N. Y.

Hughes, Edward C., Construction Engineer Providence Telephone Co., res., 34 Corinth St., Providence, R. I.

Ivens, John, Telephone Engineer, Plant Dept., American Telephone & Telegraph Co., 24 Walker St., New York, N. Y.

Jacobson, Moses, Draftsman, 145 W. 123rd St., New York, N. Y.

Johnston, Ralph A., Switchboard Sales Div., D. &. S. Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh Pa.

Koerber, George A., Professor of Electrical Engineering, Delaware College, Newark, Del.

Koo, K. P., Standardizing Laboratory, General Electric Co., Schenectady, N. Y.

***Loef, Joseph W.**, Northern Texas Traction Co., Handley; res., 109 St. Louis Ave., Ft. Worth, Texas.

Lyle, F. W., Research Laboratory, General Electric Co., Lynn, Mass.

Lyon, Jesse Daugherty, Consulting Engineer, Union Central Bldg; res., 3265 Menlo Ave., Cincinnati, O.

Nicol, D. S., Electrical Engineer, Shawinigan Water & Power Co., Montreal, Quebec.

Norgren, Carl A., Charge of Dept. of Engineering, Fairbanks, Morse & Co.; res., 3012 Marcy St., Omaha, Nebr.

***Parker, Karr**, Electrical Engineer, McCarthy Bros. & Ford, 41 Eagle St., Buffalo, N. Y.

***Raab, Harry F.**, Draughtsman, Electrical Dept., Cambria Steel Co.; res., 100 Union St., Johnstown, Pa.

Reid, Walker, Operator, Lock 12 Hydro-Electric Plant, Alabama Power Co., Clanton, Ala.

Schurig, O. R., Instructor in Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

Smith, M. A., **Jr.**, Instructor in Electrical Engineering, Trinity College, Durham, N. C.

Steinberg, E. J., Assistant Engineer, Railroad Commission of Wisconsin, 206 Stephenson Bldg., Milwaukee, Wis.

Talbot, Herbert Leslie, Chief Operator, P. E. & E. Ry. Substations, Oswego, Ore.

Taylor, N. S., Switchboard Specialist, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Thomas, H. C., Sales Engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgewood Park, Pittsburgh, Pa.

Tucker, Frank N., Electrical Engineer Ilg Electric Ventilating Co.; res., 551 E. 40th St., Chicago, Ill.

Westerwick, August, Electrical Repairman, Southern California Edison Co., Los Angeles, Cal.

***Willmore**, H. E., **Jr.**, Draughtsman, Engg. Dept., Western Electric Co.; res., 1225 S. Harding Ave., Chicago, Ill.

Woo, T. Y., Student Engineer General Electric Co., res., 27 Barrett St., Schenectady, N. Y.

Ziegler, C. E., Service Dept., Westinghouse Electric & Mfg. Co., 768 Ellicott, Sq., Buffalo, N. Y.

Total 47.

*Former enrolled Students.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1915.

Adam, E. N., Melville, Mont.
Allen, J. W. (Member), New Castle, Pa.
Armstrong, J. W. F., San Francisco, Cal.
Arsem, W. C., (Member) Schenectady, N. Y.
Benz, C. D., Los Angeles, Cal.
Bliem, H. M., San Antonio, Texas
Bosshart, H. J., Nevada City, Cal.
Bradley, H. H., Kern River, Cal.
Butlin, C. A., New York, N. Y.
Carpenter, D.E. (Member), Scranton, Pa.
Case, C. D., Chicago, Ill.
Chaney, L. P., Texas City, Tex.
Clark, J. R., Rochester, N. Y.
Coney, A. E., San Francisco, Cal.
Couper, H. W., St. Louis, Mo.
Covey, G. S., Spokane, Wash.
Coward, O. L., Seattle, Wash.
Crockett, A. S., Lynn, Mass.
Crosby, G. L., New York, N. Y.
David, B. W., Cleveland, O.
Davis, E. W., Cambridge, Mass.
Deans, W., Jr., Ithaca, N. Y.
de la Rosa, J. C., New York, N. Y.
Edgecomb, H. R., E. Pittsburgh, Pa.
Eichelberger, C. G., Cincinnati, O.
Eilers H., New York, N. Y.
Emrick, P. S. (Member), Lafayette, Ind.
Euler, H. J., New York, N. Y.
Fickel, G. R., E. Pittsburgh, Pa.
Fitz, A. E., New Hartford, Conn.
Fujita, T., Shanghai, China.
Gardiner, G. K., Portland, Ore.
Geiger, J. M., Gatun, C. Z.
Ghose, M., Schenectady, N. Y.
Graham, E. B., E. Pittsburgh, Pa.
Greenleaf, M. C., Monroe, Mich.
Griswold, L. E., Pittsburgh, Pa.
Grower, R. W., Syracuse, N. Y.
Gruen, E. C., Atlanta, Ga.
Guillou, A. V., Los Angeles, Cal.
Harden, W. H., New York, N. Y.
Hardy, N. G., Clifton, Ariz.
Heald, W. S., Keokuk, Iowa.
Heising, R. A., New York, N. Y.
Herrman, H., Ft. Wayne, Ind.
Hill, W. C., Pittsburgh, Pa.
Hosfeld, D. C., Wilmington, Del.
Hovland, H., New York, N. Y.
Howe, J. W., Cedar Rapids, Iowa.
Israel, L. L., New York, N. Y.
Keller, L. M., Rochester, N. Y.
Knight, I. W., Boston, Mass.

Leipoldt, E. V., New York, N. Y.
Lennon, R. J., Jr., Rochester, N. Y.
Leonard, L. R., Boulder, Colo.
Manley, R., Chicago, Ill.
Maurice, R., Selkirk, Man.
McBride, F. R., Portland, Ore.
McDonald, G. R., San Francisco, Cal.
McKenzie, D. A., Toronto, Ont.
McNair, J. S., Spokane, Wash.
Melcon, Z. P., Big Creek, Cal.
Melillo, R., New York, N. Y.
Meyer, J. W., Philadelphia, Pa.
Miller, H. N., Detroit, Mich.
Moore, L. J. (Member), Fresno, Cal.
Nelson, N. C., Seattle, Wash.
Olds, R. R., Belding, Mich.
Pearl, A. S., Chicago, Ill.
Phipps, A. H. C., Goldstream, B. C.
Pratt, H. B., Pittsburgh, Pa.
Ripley, C. S., Cleveland, O.
Ransom, L. L., New York, N. Y.
Rock, C. R., Binghamton, N. Y.
Rogers, A. L., New York, N. Y.
Rooker, G. N., Sandpoint, Idaho
Rosch, S. J., Bayonne, N. J.
Ruff, A. G., Philadelphia, Pa.
Sampson, E. R., E. Pittsburgh, Pa.
Schenck, C., Milwaukee, Wis.
Schumann, J. H., Detroit, Mich.
Seltzer, D., E. Pittsburgh, Pa.
Service, J. H., Stephen, Minn.
Sheppard, H. S., Ann Arbor, Mich.
Shire, W. J., New York, N. Y.
Shuey, O. R., Piedmont, W. Va.
Simon, R. J., E. Pittsburgh, Pa.
Slingman, T. D., Detroit, Mich.
Smith, C. D., Newark, N. J.
Smith, R. H., Altoona, Pa.
Snow, W. J., New York, N. Y.
Soengen, G. W., Kirkwood, Mo.
Stauffacher, E. R., Los Angeles, Cal.
Stengel, C., Wolseley, Sask.
Stephens, R. E., Follansbee, W. Va.
Stevens, P. S., St. Louis, Mo.
Story, R. A., Vancouver, B. C.
Tanaka, T., Tokyo, Japan
Thomas, W. R., Wenatchee, Wash.
Tillotson, C. C., Butte, Mont.
Werwerth, O. (Member), Milwaukee, Wis.
Whipple, C. A., Hillsboro, Tex.
Whitaker, D. A., Evanston, Ill.
White, W. C., Memphis, Tenn.
Widdows, R. G., New York, N. Y.
Wilke, R. C., Milwaukee, Wis.
Wilson, A. W., 3rd, Philadelphia, Pa.
Wilson, E. W. (Member), Panama, R.P.
Wyatt, F. D., New York, N. Y.
Zima, L. A., New York, N. Y.

Total 110.

Students Enrolled December 11, 1914

6858 Packer, L. C., Ohio State Univ.
6859 Wilson, J. E., Ohio State Univ.
6860 Harter, L. J., Ohio State Univ.
6861 Brown, R. Q., Univ. of Wash.
6862 Baer, H. E., Univ. of Wash.
6863 Palmer, G. S., Univ. of Wash.
6864 do Amaral, J. P., Ohio Northern Univ.
6865 Fong, G. Y., Mass. Inst. Tech.
6866 Meyer, C. P., Univ. of Missouri
6867 Zindel, R. C., Univ. of Pittsburgh
6868 Kratzert, G. M., Univ. of Pitts.
6869 Dana, H. J., Wash. State College
6870 Dingledine, R. K., Ohio St. Univ.
6871 Savage, E. W., Univ. of Toronto
6872 das Neves, J. G. F., Ohio Northern University
6873 Bussiere, A., Ohio Northern Univ.
6874 Whelan, J. M., W. Virginia Univ.
6875 Summers, H. S., W. Virginia Univ.
6876 Walker, C. L., W. Virginia Univ.
6877 Schramm, H.C., W. Virginia Univ.
6878 Schaffer, W., W. Virginia Univ.
6879 Adams, C. S., W. Virginia Univ.
6880 Hormell, D. O., W. Va. Univ.
6881 Huffman, C. R., W. Va. Univ.
6882 Madigan, F., W. Va. Univ.
6883 Riheldaffer, W. A., W. Va. Univ.
6884 Wilcoxen, M., W. Va. Univ.
6885 Kirk, I. M., Iowa State College
6886 Nagle, C. F., Iowa State College
6887 Seeds, E. C., Iowa State College
6888 Godown, E., Iowa State College
6889 Kenneally, M. M., Iowa St. Coll.
6890 Jones, M. F., Univ. of Arkansas
6891 Dunn, J. H., Univ. of Arkansas
6892 Hopper, D. C., Univ. of Arkansas
6893 Bell, J. E., Univ. of Arkansas
6894 Malone, R. G., Ga. School Tech.
6895 Duerr, L. C., Univ. of Pittsburgh
6896 Shepard, J. A., Stanford Univ.
6897 Guy, R. W., McGill University

6898 Smith, H. E., Armour Inst. Tech.
6899 Noyes, B., Jr., W. Va. Univ.
6900 Sydenstricker, C. R., W. Va. Univ.
6901 Dean, D. M., W. Va. Univ.
6902 Nelson, M. C., W. Va. Univ.
6903 Harper, H. M., W. Va. Univ.
6905 Seckman, J. R., W. Va. Univ.
6906 Newell, J. H., Ohio North. Univ.
6907 Cone, W. L., Stanford University
6908 Patterson, G. R., Univ. of Pitts.
6909 Reid, W. E., Columbia Univ.
6910 Wilson, G. M., Purdue Univ.
6911 Lam, N., Purdue University
6912 Wright, B. S., Purdue University
6913 Holman, H. R., Purdue Univ.
6914 Fisher, H. H., Purdue Univ.
6915 Flora, J. H., Kans. St. Agri. Coll.
6916 Usselman, G.L., Kans.St.Agri.Coll.
6917 Knowles, T.R., Kans. St. Agri.Coll.
6918 Fell, S. G., Kans. St. Agri. Coll.
6919 Tate, D. C., Kans. St. Agri. Coll.
6920 Baker, R. G., Kans. St. Agri. Coll.
6921 Archer, C. L., Kans. St. Agri. Coll.
6922 Hooker, C. A., Kans. St. Agri. Coll
6923 Goudy, M., Kans. St. Agri. Coll.
6924 Hultgren, C.D., Kans.St.Agri.Coll.
6925 Deal, W. E., Kans. St. Agri. Coll.
6926 Cook, W. A., Univ. of Pittsburgh
6927 Azevedo, F. J., Ohio North. Univ.
6928 Slater, H..C., Yale University
6929 Stortz, R., Pratt Institute
6930 Haggott, W. S., Univ. of Illinois
6931 Trautman, D.L., Carnegie In.Tech.
6932 Headings, W.W., Carnegie In.Tech.
6933 Bare, L. M., Wash. University
6934 Lieber, C. A., Wash. University
6935 Dorfman, L., Univ. of Texas
6936 Fritz, H. R., Univ. of Texas
6937 Ayus, W. F., Univ. of Texas
6938 v. Blucher, R. A., Univ. of Texas
6939 Bailey, C. L., Univ. of Texas
6940 Smith, E., Univ. of Texas
6941 Thompson, R. P., Univ. of Texas
6942 Delhomme, L. K., Univ. of Texas
6943 Mead, A., Univ. of Michigan
6944 Guilbault, R. B., Univ. of Mich.
6945 Skwor, L. E., Univ. of Michigan
6946 Gardella, A., Univ. of Michigan
6947 France, W. H., Univ. of Mich.
6948 Stecher, H. D.. Univ. of Mich.
6949 Howell, G. H.. Univ. of Mich.
6950 Raemsch, W. P., W. Va. Univ.
6951 Curtis, R. E., Mass. Inst. of Tech.
6952 Watters, A. C., Columbia Univ.
6953 Friedenthal, C.G.F., Univ. of Wash.
6954 Loomis, W. J., Kans. St. Agri. Coll.
6955 Smith, G. B., Jr., Univ. of N. C.
6956 Joyner, W. H., Univ. of N. C.
6957 Miller, C., Univ. of N. C.
6958 Elsom, F. H., Univ. of N. C.
6959 Chu, Y. M., Mass. Inst. of Tech.
6960 Mizushi, F. M., Cornell Univ.
6961 Cole, I. E., Cornell Univ.
6962 Graham, R. W., Cornell Univ.
6963 Robbins, F. J., Cornell Univ.
6964 Dedlow, C., Cornell University
6965 Homan, A. G., Cornell Univ.
6966 Hukill, H. D., Cornell University
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6968 Sharp, H. M., Cornell Univ.
6969 Cobb, H. E., Cornell Univ.
6970 Yang, S. Z., Cornell Univ.
6971 Krouse, R. L., Cornell Univ.
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6973 Frazer, L. S., Cornell Univ.
6974 Sutcliffe, H. T., Cornell Univ.
6975 Millard, E. H., Cornell Univ.
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6987 Phillips, V. B., Cornell Univ.
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6989 Homer, E. C., Cornell Univ.
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7002 Wiley, H. W., Cornell Univ.
7003 Rice, W. H., Cornell Univ.
7004 Moore, J. H., Cornell Univ.

7005 Stotz, J. K., Cornell Univ.
7006 Woodbury, N. B., Cornell Univ.
7007 Davidson, B. G., Cornell Univ.
7008 Green, W. S., Cornell Univ.
7009 Maenak, W., Cornell Univ.
7010 Siler, L. N., Cornell Univ.
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7027 Nilsen, P. J., Univ. of Illinois
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Total 171.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Vacancies

V-54. Foreman Electrician. A large electrical manufacturing company, located in Massachusetts, has an opening for an electrician to keep up repairs of electrical apparatus in the shop plant. He would have the work of repair on 110-220-volt a-c. lighting circuits, 550-volt two-phase motor circuits, transformers and 2300-volt two-phase power circuits; also disconnecting and reconnecting apparatus moved to different places in the factory. Would have about fifteen men in his charge. Fifty-five hours and $25 per week.

The United States Civil Service Commission announces an open competitive examination for electrical draftsman on February 3 and 4, 1915, at many places throughout the United States mentioned in Circular No. 62, issued December 19, 1914, which gives full information and may be obtained by addressing the Commission at Washington, D. C. From the register of eligibles resulting from this examination certification will be made to fill vacancies in this position as they may occur at United States Navy Yards and naval establishments or in the Department at Washington, D. C., at entrance salaries ranging from $3.52 to $5.52 per diem, unless it is found to be in the interest of the service to fill any vacancy by reinstatement, transfer or promotion.

The duties of this position require the origination and supervising preparation of electrical installation plans aboard ship, power, lighting, interior communication, radiotelegraphy, the designing of switchboards, writing up specifications for apparatus, estimating, checking plans, etc.; writing up descriptions, instructions for use, care and maintenance of the apparatus, and systems indicated above.

Men Available

149. Electrical-Mechanical Engineer (Degree B.E. 1907). 2½ years General Electric testing and engineering. With other organizations experience covers steam turbine and hydroelectric plants, distribution and transmission systems up to 110,000 volts; designing, superintending construction, operation, and reports on properties.

150. Field Engineer. Technically educated; two years drafting; three years dynamo testing; six years investigation and erection for large manufacturing companies. One and a half years of operation and maintenance with Spanish labor. Can qualify as resident electrical engineer or superintendent of power or lighting system. No objection to foreign service.

151. Electrical Engineer. Graduate of State College of Washington, 1908, is open for engagement. Five years' experience in the testing and distribution departments of a large electric light and power company on the Pacific coast. Can give best of references.

152. Electrical Engineer. Mass. Inst. Tech. graduate. Two years General Electric testing and industrial control engineering. With Boston Edison Co. as conduit engineer and with the Walworth Mfg. Co. as efficiency engineer. Prefer employment as engineer in manufacturing company or textile mill.

153. Electrical Engineer. Twelve years' experience in design, construction, and management of electric light, power and railway properties. Thoroughly familiar with estimates, reports, accounting systems, rates, etc. Has held positions of designing engineer, construction superintendent, and general manager. Capable of handling employes and successful in dealing with the public.

154. Mechanical and Electrical Engineer. Graduate; 29 years of age; married. Three years' machine shop and erecting experience. Six years' drafting, assistant electrical engineer with crane concern, and mechanical engineering experience on industrial, switchboard and railway apparatus. First-class references.

155. Electrical Engineer. Recent graduate of a leading Eastern university. Experienced in central station management, operation and maintenance; possesses good executive ability and can furnish first-class references. Desires position affording opportunity for advancement.

156. Electrical Inventor and Investigator. A progressive electrical engineer (32) of unusually broad experience and full of original ideas. Skilled in developing new or incomplete ideas to a commercial form or executing any sort of original work involving electricity and mechanics. Invite correspondence with thriving concern with unusual problems to solve.

157. Electrical Engineer. Young man, technical graduate, two years General Electric test and two years in sales dept. of district office. Has also served six months as meter-man with public service corporation. Desires permanent position with operating or manufacturing company. Pacific coast or Middle West preferred.

158. Electrical Engineer. Two years General Electric test; three years service inspection and overhead distribution engineering with large central station. Two years Panama Canal as wireman and foreman on installation of electrical equipment for lock operation. Desire management of small electrical property but open to any good offer. Now available.

159. Technical Graduate seeks connection with small manufacturing concern, contractor or commercial department of central station. Thorough training in sales and office routine; several years testing and construction in the field for prominent electrical manufacturing company. Age 25; energetic, and of pleasing personality. Best of references from present employers.

160. Electrical Engineer. Over twelve years' experience in design, construction and operation of low- and high-tension power plants and substations. Would like position as superintendent of power and lighting plant in small city, Middle West preferred. At present employed.

161. Electrical Engineer. Age 32, technical education, ten years' practical experience. Expert on management of construction and operation of electrical apparatus connected with large industrial plants. Can show efficiency with minimum cost and delay. Now connected in above capacity. Best of credentials; location no object.

162. Electrical Engineer. Graduate Drexel Institute; seven years construction and operation of power plants and lines; considerable experience in lead cable work; three years in charge high-tension (substation and line) work in Canada. Desires position as superintendent of construction or superintendent in charge of municipal plant. A-1 references.

163. Electrical Engineer. Eight years' experience shop work, hydroelectric and steam-electric powerhouse superintendency, substation and underground system design, managing and engineering municipal systems. Now manager and chief engineer hydroelectric and waterworks department of large Canadian city. Thoroughly familiar with hydroelectric power commission's system of Ontario.

164. Electrical Engineer. Technical post-graduate from a Middle-West and also from an Eastern school. Experience includes six years of teaching in two large universities and nearly four years of technical and executive work for operating companies.

165. Superintendent and Electrical Engineer. Has constructed generating and transforming stations of all capacities, systems and voltages up to 110,000; also mechanical and structural work in connection therewith, and along other lines, including bridges and hoists; wishes change for personal reasons.

166. Young man, graduate E. E. 1914, experienced in electric light and telephone construction work. At present employed as operator in a large power plant. Desires position in engineering department or construction work of power company or small manufacturer. Can leave on short notice. Middle West preferred. References.

167. Electrical Engineer. Technical graduate of Western university, 1910. Experience includes one and a half years General Electric test and laboratory work, and more than two years designing transformers, mostly for special purposes, such as testing, etc. Have also had some construction experience. Can give best of references.

168. Electrical Engineer. Fourteen years' experience testing, engineering, construction and operation with prominent manufacturing and public service companies; engineer and superintendent on construction and operation of railway, lighting, power stations and transmission systems. Age 35; at present engaged on operating work in East. Position desired with progressive company offering opportunity for advancement.

169. Electrical Engineer, technical graduate, married. Ten years experience with light and power companies on power plant operation, high-tension transmission, distribution, and commercial department. Desires position as superintendent of light and power company. Past employers as references. Now employed.

170. Electrical Engineer and Motor Specialist. Technical graduate; two years testing experience General Electric Co., three years in A-C. Eng'g. Dept. on motor design and application. Two years as designing engineer in large Canadian electric manufacturing company. Well acquainted with industrial motors and control. Employed but can leave on short notice.

171. Technical Graduate. Two and a half years at Mass. Institute of Technology; three years with General Electric Co. special testing on small motors and generators; two years with Holtzer-Cabot Co.; short time with large construction and engineering company.

172. Plant Electrician. Good education; practical experience in factory electrical work; twenty years in the electrical industry. In charge of 500 h.p. factory plant for 2½ years. Age 41, family, steady habits, trustworthy. Employed, can leave on short notice. Good references. Willing to go anywhere.

173. Graduate Electrical Engineer. Five years' experience with a-c. and d-c. motors in manufacturing, testing, experimental, drafting, also executive. Desire position in engineering department of concern manufacturing motors. Good references.

174. Electrical Engineer, graduate from leading Eastern technical school June, 1914. Woud like to locate with some manufacturing or construction company where practical experience may be obtained.

175. University graduate, 26 years of age. One year and a half in drawing room, six months as electrician with light and power company. Position with railway or power company preferred. Now employed.

176. Graduate Electrical Engineer. Four years' practical shop and erection experience; three years in the design of various electrical apparatus and motors; five years in laying out light and power plants, substations, high-tension and low-tension, switching equipments, etc. Best references.

177. Advertising Manager. Open for engagement after Feb. 1. Technical graduate; with General Electric Co. three years in shop and office; with leading general advertising agency in Philadelphia four years; with prominent Eastern central station as advertising manager until outbreak of European war. Salary desired is reasonable.

178. Electrical Engineer. Technical graduate; age 28. Six years' experience with Bell Company, including three years in construction and maintenance work, and three years in telephone engineering. Familiar with field and est-imate work. Best of references.

179. Electrical Engineer. Single, age 32. Twelve years' experience hydroelectric construction and operation, also as master mechanic and chief electrician in mine. Speak and write Spanish; four years in Mexico. Prefer foreign service. Employed now but can leave on short notice. Best of references.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Institute of Chemical Engineers. Transactions, vol. VI, 1913. New York. 1914. (Gift of Institute.)

American Institute of Electrical Engineers. Transactions vol. XXXII, pt. 1-2. New York, 1913. (Gift.)

Le Courant Continu. Cours d Electricité Industrielle. By Franz Magonette. Paris, 1914. (Purchase.)

Edison Storage Battery (1910). By Walter E. Holland. New York, 1910. (Gift of author.)

Electric Cooking, heating and cleaning. By Maud Lancaster. New York, 1914. (Purchase.)

Electric Power Club. Executive Staff, Member companies, Committees, Constitution and By-laws, Standards, Nomenclature, Index. 1914. (Gift of Electric Power Club.)

Electrical Practice in Colleries. Ed. 4. By Daniel Burns. London, 1914. (Purchase.)

Electricity at High Pressures and Frequencies. By H. L. Transtrom. Chicago, 1913. (Purchase.)

Electricity in Coal Mining. By D. R. Shearer. New York, McGraw-Hill Book Co., 1914. (Gift of author.)

This small work has been prepared to cover, in a general way, the many phases of electrical engineering, as applied to coal mining. It covers power plant, haulage, coal cutting machinery, the electric operation of fans and pumps, and bell and signal systems. W. P. C.

Elektric Lighting Connections. By W. P. Maycock. London, A. P. Lundberg & Sons, 1914. (Gift of publishers.)

The third edition of this vest pocket edition, of a handbook of switching connections. W. P. C.

Elektrodengrösse und Durchschlagsspannung bei, der Prüfung dünner Isolierstoffe. By H. Gewecke und W. v. Krukowski. (Reprint from Archiv fur Elektrotechnik, III Band, 1914.) (Gift of H. Gewecke.)

Engineering Directory, 1914. Chicago, 1914. (Purchase.)

Kennelly Reprints, vol. 7, 1913-14. N.p. n.d. (Gift of A. E. Kennelly.)

Moulded Insulation. Boonton, 1914. (Gift of Boonton Rubber Mfg. Co.)

National Electric Light Association. 37th Annual Convention Philadelphia, June 1914. 4 vols. New York, 1914. (Exchange.)

Principles and Practice of Electrical Engineering. By Alexander Gray. New York, 1914. (Purchase.)

Principles of Electric Wave Telegraphy and Telephony. Ed. 2. By J. A. Fleming. London-New York, 1910. (Purchase.)

Die Quarzlampe; ihre Entwicklung und ihr heutiger Stand. By J. C. Pole. Berlin, 1914. (Purchase.)

La Telephonie Automatique. By H. Milon, Paris, 1914. (Purchase.)

La Téléphonie et les autres moyens d'Intercommunication. By P. Maurer. Paris, 1914. (Purchase.)

U. S. Bureau of Standards. Scientific Papers Decennial Index to the Bulletin, vols. 1-10 1904-14. Washington, 1914. (Exchange.)

Westinghouse Electric & Manufacturing Company. Annual Report, 1914. (Exchange.)

Die wirtschaftlich günstigste Spannung fur Fernübertragungen mittelst Freileitungen. By Helmuth Eimer. Berlin, 1914. (Purchase.)

TRADE CATALOGUES

Chelten Electric Co. Philadelphia, Pa. "Chelten" electrical specialties. 1915.

Chicago Pneumatic Tool Co. Chicago Ill. Bulletin No. 34-S. Small power driven compressors. 1914.

Delta Star Electric Co. Chicago, Ill. Bulletin 14. Outdoor sub-stations and weather-proof equipment. Oct., 1914.

General Electric Co. Schenectady, N. Y. Bulletin No. 40500. Alternating current generators for direct connection to reciprocating engines. Nov., 1914.

——No. 41500. Small direct and alternating current motors drawn shell type. Nov., 1914.

National Lamp Works of General Electric Co. Cleveland, O. Bulletin No. 22. Show case lighting.

Wagner Electric Manufacturing Co. St. Louis, Mo. Bulletin 106. Single-phase motors. Dec. 1914.

UNITED ENGINEERING SOCIETY

American Road Builders' Association. Proceedings of Annual Convention 9th, 10th. New York, 1912-13. (Gift of Association.)

American Scenic and Historic Preservation Society. Annual Report 19th, 1914. Albany, 1914. (Gift of American Scenic & Historic Preservation Society.)

Comparison of certain physical properties of nickel steel and carbon steel proving the superiority of nickel steel over carbon steel for bridge and structural purposes. By Albert Ladd Colby, July 1903. n.p. n.d. (Gift of International Nickel Co.)

International Library of Technology. Manufacture of Gas, Iron, Steel and Cement. vol. 104. Scranton, n.d. (Purchase.)

List of works in the New York Public Library relating to oxy-acetylene welding. New York 1914. (Gift of W. B. Gamble.)

Manual of Practical Potting. Edited by C. F. Binns. London, 1907. (Purchase.)

Manufacture of Mineral and Lake Pigments. By Josef Bersch. London, 1901. (Purchase.)

Les Manuscrits de Leonard de Vinci. By Chas. Ravaisson-Mollien. 6 vols. Paris, 1881. (Purchase.)

New York Times Index, vol. 3, 1914. New York, 1914. (Purchase.)

Oil Colours and Printers Inks. By L. E. Andes. London, 1903. (Purchase.)

Principles and Practice of Dipping, Burnishing, Lacquering and Bronzing Brass Ware. Ed. 2. By W. N. Brown. London, 1912. (Purchase.)

Reinforced Concrete Construction, vols. 1-2. By G. A. Hool. New York, 1912. (Purchase.)

Société Technique de L'Industrie du Gaz. Compte-rendu du Quarantième Congrès 1913, Toulouse. Paris, 1913. (Gift of American Gas Institute.)

United States Steel Corporation. Annual Report. 6th-12th, 1907-1913. Hoboken, N-J., 1907-13. (Gift of U. S. Steel Corporation.)

Zeitschrift für Kleinbahnen. Vol. 1, nos. 1, 3-8; vols. 3-5; vol. 6, nos. 2-12; vols. 7-8. Berlin 1894, 1896-1901. (Purchase.)

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Revised to Jan. 1, 1915

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Revised to January 1, 1915.

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Baltimore Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Building, Baltimore, Md.
Boston Feb. 13, '03	G.W. Palmer, Jr.	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago 1893	E. W. Allen	W. J. Norton, 112 W. Adams St., Chicago, Ill.
Cleveland Sept. 27, '07	Howard Dingle	R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio.
Detroit-Ann Arbor Jan. 13, '11	H. H. Norton	Ray K. Holland, Cornwell Building, Ann Arbor, Mich.
Fort Wayne Aug. 14, '08	L. D. Nordstrum	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Indiana.
Indianapolis-Lafayette Jan. 12, '12	J. L. Wayne, 3d.	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell University, Ithaca, N.Y.
Los Angeles May 19, '08	C. G. Pyle	Edward Woodbury, Pacific Lt. & Pr. Company, Los Angeles, Cal.
Lynn Aug. 22, '11	W. H. Pratt	F. S. Hall, General Electric Co., Lynn, Mass.
Madison Jan. 8, '09	J. W. Shuster	F. A. Kartak, Univ. of Wisconsin, Madison, Wis.
Mexico Dec. 13, '07		
Milwaukee Feb. 11, '10	L. L. Tatum	W. J. Richards, National Brake and Electric Co., Milwaukee, Wis.
Minnesota Apr. 7, '02	Leo H. Cooper	Emil Anderson, 1236 Plymouth Bldg., Minneapolis, Minn.
Panama Oct. 10, '13	Hartley Rowe	Clayton J. Embree, Balboa Heights, C. Z.
Philadelphia Feb. 18, '03	H. F. Sanville	W. F. James, 1115 North American Bldg., Philadelphia, Pa.
Pittsburgh Oct. 13, '02	J. W. Welsh	Charles R. Riker, Electric Journal, Pittsburgh, Pa.
Pittsfield Mar. 25, '04	W. W. Lewis	M. E. Tressler, General Electric Company, Pittsfield, Mass.
Portland, Ore. May 18, '09	R. F. Monges	Paul Lebenbaum, 45 Union Depot, Portland, Ore.
Rochester Oct. 9, '14	John C. Parker	O. W. Bodler, Pittsford, N. Y.
St. Louis Jan. 14, '03	S. N. Clarkson	A. McR. Harrelson, 5929 DeGiverville Avenue, St. Louis, Mo.
San Francisco Dec. 23, '04	C. J. Wilson	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady Jan. 26, '03	H. M. Hobart	S. M. Crego, Gen. Elec. Co., Schenectady, N. Y.
Seattle Jan. 19, '04	S. C. Lindsay	E. A. Loew, University of Washington, Seattle, Wash.
Spokane Feb. 14, '13	J. W. Hungate	L. N. Rice, Parsons Hotel, Spokane, Wash.
Toledo June 3, '07	George E. Kirk	Max Neuber, Cohen, Friedlander & Martin, Toledo, O.
Toronto Sept. 30, '03	D. H. McDougall	H. T. Case, Continental Life Bldg., Toronto, Ont.
Urbana Nov. 25, '02	I. W. Fisk	P. S. Biegler, University of Illinois, Urbana, Illinois.
Vancouver Aug. 22, '11	E. P. LaBelle	K. C. Auty, B. C. Electric Railway Co. Ltd., Vancouver, B. C.
Washington, D. C. Apr. 9, '03	C. B. Mirick	C. A. Peterson, 1223 Vermont Ave., N. W. Washington, D. C.

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LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas Nov. 12, '09	J. F. Nash	A. Dickie, A. & M. College, College Station, Tex.
Alabama, Univ. of Dec. 11, '14		
Arkansas, Univ. of., Mar. 25, '04	D. C. Hopper	J. B. Bell, Univ. of Arkansas, Fayetteville, Ark.
Armour Institute Feb. 26, '04	W. L. Burroughs	Chester F. Wright, 3341 Michigan Boulevard, Chicago, Ill.
Bucknell University May 17, '10	F. O. Schnure	J. M. Hillman, Bucknell University, Lewisburg, Pa.
California, Univ of., Feb. 9, '12	L. R. Chilcote	E. S. Meddaugh, 2521 Channing Way, Berkeley, Cal.
Cincinnati, Univ. of Apr. 10, '08	F. Oberschmidt	A. C. Perry, 707 East McMillan Street, Cincinnati, O.
Clemson Agricultural College Nov. 8, '12	W. E. Blake	F. F. Dargan, Clemson College, S. C.
Colorado State Agricultural College Feb. 11, '10	George M. Strecker	E. O. Marks, Colorado State Agricultural College, Fort Collins, Colo.

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Colorado, Univ. of.,.....Dec. 16, '04	Philip S. Borden	Charles S. Miller, University of Colorado, Boulder, Colo.
Georgia School of Technology..............June 25, '14	R. A. Clay	J. M. Reifsnyder, Jr., Georgia School of Technology, Atlanta, Ga.
Highland Park College Oct. 11, '12	Clyde Prussman	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa.
Idaho, University of....June 25, '14		
Iowa State College.....Apr. 15, '03	Roscoe Schaffer	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.,........May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col.,. Jan. 10, '08	L. V. Fickle	Clarence E. Reid, Kansas State Agric.Col., Manhattan, Kan.
Kansas, Univ. of.,......Mar. 18, '08	Ray Walker	Ernest Arnold, Univ. of Kansas, Lawrence, Kansas.
Kentucky State Univ. of Oct. 14, '10	Harry Y. Barker	G. F. Campbell, 345 South Limestone Street, Lexington, Ky.
Lafayette College......Apr. 5, '12	R. McManigal	W. J. English, Jr., Lafayette College, Easton Pa.
Lehigh University,......Oct. 15, '02	N. F. Matheson	F. C. Brockman, 3 North Main St., Nazareth, Pa.
Lewis Institute,........Nov. 8, '07	A. H. Fensholt	Fred A. Rogers, Lewis Institute, Chicago, Ill.
Maine, Univ. of.,.......Dec. 26, '06	H. H. Beverage	W. E. Bowler, University of Maine, Orono, Maine.
Michigan, Univ. of.,....Mar. 25, '04	H. A. Enos	H. W. Stubbs, University of Michigan, Ann Arbor, Mich.
Missouri, Univ. of.,.....Jan. 10, '03	E. W. Kellogg	K. Atkinson, University of Missouri, Columbia, Mo.
Montana State Col.,....May 21, '07	John M. Fiske	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A, Lincoln, Nebr.
New Hampshire Col....Feb. 19, '09		
North Carolina Col. of Agr., and Mech. Arts......Feb. 11, '10	H. M. Alexander	G. G. McArn, West Raleigh, N. C.
North Carolina, Univ. of Oct. 9, '14	P. H. Daggett	J. W. McIver, University of North Carolina, Chapel Hill, N. C.
Ohio Northern Univ.,...Feb. 9, '12	R. E. Lowe	W. F. Schott, 426 South Union Street, Ada, Ohio.
Ohio State Univ.,.......Dec. 20, '02	Leslie J. Harter	Robert C. Schott, 38 14th Avenue, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col...........Oct. 13, '11	A. P. Little	Quentin Graham, 118 Husband St., Stillwater, Okla.
Oklahoma, Univ. of.,...Oct. 11, '12	C. K. Karcher	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon, Agr. Col.,......Mar. 24, '08	W. R. Grasle	Winfield Eckley, Oregon Agric. Col,, Corvallis, Ore.
Penn State College.....Dec. 20, '02	H. S. Smith	Daniel E. Winslow, State College, Pa.
Pittsburgh, Univ. of.,...Feb. 26, '14	B. E. O'Hagan	George Hickman, University of Pittsburgh, Pittsburgh, Pa.
Purdue Univ.,..........Jan. 26, '03	L. W. Spray	R. E. Tafel, Purdue Univ., Lafayette, Ind.
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	W. E. Coover, 74 Eagle Street, Troy, N.Y.
Rose Polytechnic Inst., Nov. 10, '11	Warren F. Turner	F. Edward Bundy, 1103 N. 8th Street, Terra Haute, Ind.
Rhode Island State Col. Mar. 14, '13	W. C. Miller	P. M. Randall, Jr., Rhode Island State College, Kingston, R. I.
Stanford Univ.,........Dec. 13, '07	G. L. Beaver	H. J. Scholz, Stanford University, Cal.
Syracuse Univ.,.........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.,.......Feb. 14, '08	J. M. Bryant	J. A. Correll, University of Texas, Austin, Tex.
Throop College of Technology..............Oct. 14, '10	W. L. Newton	A. W. Wells, Throop Poly. Institute, Pasadena, Cal.
Virginia, Univ. of.......Feb. 9, '12	W. S. Rodman	H. Anderson, Jr., 1022 West Main St., Charlottesville, Va.
Wash., State Col. of....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash., Pullman, Wash.
Washington Univ........Feb. 6, '04	C. C. Hardy	Charles P. Seeger, Washington University, St. Louis, Mo.
Washington, Univ. of.,. Dec. 13, '12	H. W. McRobbie	B. B. Bessesen, Univ. of Washington, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly. Inst., .Mar. 25, '04	Frank Aiken	A. B. R. Prouty, Worcester Poly. Inst., Worcester, Mass.
Yale University........Oct. 13, '11	F. M. Doolittle	K. Lessey, 106 Van. Sheff, New Haven, Conn.

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of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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To be presented at the meeting of the San Francisco Section of the American Institute of Electrical Engineers, San Francisco, Cal., January 22, 1915.

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(*Subject to final revision for the Transactions.*)

THE BEST CONTROL OF PUBLIC UTILITIES

BY FRANK G. BAUM

ABSTRACT OF PAPER

The author states as an axiom that "the best control of a public utility is that which develops an eagerness and ability on the part of the company to furnish the service, and an equal eagerness and ability on the part of the consumer to purchase the service." Five elements requisite for the development of this eagerness and ability on the part of the company and the consumers are stated and analyzed.

One of the important elements is confidence in the company and its rates, and the author states his conviction that class rates are absolutely necessary for the best development of the business. All classes of consumers benefit by a diversified use of electric energy, which makes lower rates possible. The principle at the bottom of all rates is to make the plant earn all it can during every hour of the day so that the burden of the investment may be distributed. The same principle applies to nearly all public utilities, railroad, telegraph, express and postal service.

There is confusion in the minds of consumers because rates for power are lower than rates for electric lighting, and the electric energy for the two very different kinds of service is measured in the same units, kilowatt-hours. But in the similar case of railway service, there is no feeling that passengers should be carried as cheaply as freight, because it is realized that the two kinds of service are very different, and one is measured in passenger-miles and the other in ton-miles. Therefore the author urges the establishment of class rates for electric service as being more scientific than the methods in general use at present, and less likely to lead to misunderstanding. Examples are given to show that the lighting consumer's rate must be much higher than the power consumer's, because the investment and cost of operation to serve the former are greater than are required to serve the latter, and because, for the same peak demand, the total energy used by the power consumers is much greater than that used by the lighting consumers. The paper outlines the method for determining class rates for different classes of service.

IT MUST be evident to anyone who has given serious consideration to the subject of the control of public utilities that it is necessary always to have in mind the following as an axiom:

The best control of a utility is that which develops an eagerness and ability on the part of the company to furnish the service, and an *equal* eagerness and ability on the part of the consumer to purchase the service.

Manuscript of this paper was received November 27, 1914.

Note that there must be both eagerness and ability on each side in order to promote the best interests of the business. Now how are we to determine the best way in which to develop this eagerness and ability on the part of the company and the consumer?

1. There must be developed a diversified use of electric energy.

2. Fair public service commissions must act as boards of arbitration between the company and the consumer.

3. The rate of return on the investment must be liberal.

4. There must be confidence in the company and its rates, and *class rates* are absolutely necessary for the development of the business.

5. There must be some incentive for the company to make economies in construction and operation.

It will be profitable to review these five requisites in some detail and try to make clear some of the points now causing confusion in the minds of some consumers and investors.

(1) It is necessary for the company to know the possibilities of the use of electricity in its territory and incessantly encourage the use of this form of power throughout its territory. It need hardly be explained that the fundamental characteristic of electricity as an aid to human endeavor is that it can be produced at certain central points and distributed by means of electric wires throughout a tremendous area. It is thus carried to every place where power or light is needed, the original power being divisible into an infinite number of parts, each part performing its function at its proper place in a perfectly predetermined and efficient manner. Also it must be understood that electricity cannot be stored in large quantities, but must be produced the instant it is used.

It is also well to bear in mind that most labor or effort can be stated in terms of energy, and when power can be applied to displace physical energy there is almost always a very large gain in efficiency and especially in output. And always when the larger efforts required are done by power instead of by human labor, the result is a stimulation of other industries. For example, when a railroad takes the place of teams for hauling between certain points, the cheaper method of hauling becomes a primary cause for the establishment of other industries which were not practical before the advent of the railroad. Similarly, cheap power in a district is generally a primary cause for the establishment of other industries not possible before the advent of cheap power. The result is that railroads and electric power lines, which, like steamship lines, are primary causes of the establishment of other industries and tend to promote general prosperity, should be encouraged, if not subsidized. Illustrations of the advantages to all consumers of a diversified business will be given under (4).

(2) In the determination of what is the best policy for a public service company, the question of the proper rates for different kinds of service is often a matter of contention between the company and the consumer, and as the service which a railroad or a power company furnishes is a natural monopoly, and competition does not promote the eagerness desired on the part of the consumer or of the company to purchase or furnish the service, the regulation of the rates is now generally delegated to public service commissions, which are really boards of arbitration to determine what is for the best interests of the business, considering both the company and the consumer.

(3) In the determination of reasonable rates for service the commissions, in addition to the ordinary operation and maintenance expenses, take account of the capital invested, and capitalize the loss in interest covering the unproductive period during which the business was being established, and allow generally some capitalization of the going value of the business, the latter often being made up of a number of elements, some of which are difficult to determine with great exactness. The result is that rates are usually allowed liberally so as to leave no doubt of the above items, and quite generally when this is done there is no resort to the courts. The rate of return must, of course, depend on the risk, the character of the country, the stability of the business, and the economy of the manufacture of the power facilities.

While a rate of return is generally allowed for the initial period of a company's business, no extra return from business originating on new extensions is generally allowed. The reluctance of companies to make extensions into new territory is largely due to this fact. As a matter of fact, all extensions into new territory should be treated as unprofitable for such period as is necessary for them to become paying, and a capitalization of the losses should be allowed the same as in the establishment of a new enterprise.

The amount of time necessary for a business to become remunerative may vary from one to ten years, and generally if one can start and produce a paying enterprise in five years it may be considered a success. If the earnings commence at zero and become remunerative at the end of six years, the loss in interest amounts to about 18 per cent of the investment. All unremunerative extensions should be treated in the same way, with the result that from 10 to 20 per cent capitalization should be allowed on the total investment in order to promote extensions by the established companies. Otherwise the result will be, if no allowance is made for extensions, that the established companies will not make extensions into new territory, but these will be undertaken instead by new companies which will be allowed to capitalize the loss in interest at a higher rate than the established companies. Extensions into new districts are extremely important, because we must not only consider those who enjoy the service, but those who would like to make use of the same service.

As an example, I have a ranch located 35 miles from the nearest railroad point. The Southern Pacific Company surveyed a line five years ago, but owing to general conditions has never built the line. Now, a reduction of freight or passenger rates to the valley farmers is no help to me; in fact the reduction to the valley farmers may be one of the reasons I do not get railroad service. Moreover, I am not much concerned whether or not the rates to be charged me during the first ten years are 20 per cent higher than they will be later. What I want is railroad service and I am willing to pay high rates and a bonus to get it. The district has as much available land as the Imperial Valley and can support a railroad, but I and the other farmers do not get the railroad service because there is no incentive for the railroad to go into new territory.

All the early companies risked large sums in the early stages of the electrical business and this should not be lost sight of in fixing rates at the present time. A certain manufacturing company at one time had a possible loss of about $10,000,000 facing it before it made its type of steam turbine a success. The price at which turbines are sold must, of course, absorb this amount, but the gain in efficiency obtainable, of which the public gets the benefit, makes the $10,000,000 insignificant. If the manufacturers are entitled to something for their risk, is not the electricity supply company that installed reciprocating engines to be replaced by turbines entitled to something for its risk? Usually we penalize the company and make it stand the loss on its books. Another manufacturing company stood to lose at one time about $500,000 before the induction motor was made a success. It is certainly entitled to a large return for this risk, especially when we consider the enormous value of the induction motor to the world. Similarly the early transmission companies stood to lose the entire first investments made. And yet, in spite of the enormous value of this pioneer work, we hear many people who say there shall be a return only on the wise investment. Who is to judge what was a wise investment in water power twenty years ago?

(4) If all classes of service were of the same kind there would be little difficulty in arriving at rates that would satisfy the company and the public, but where the same service is used for various purposes, the rates for the service vary, the public is confused and generally considers that it is being treated unjustly. For example, a man using electricity to light his residence pays a rate of say 10 cents per kilowatt-hour, but a man who uses electric power to run an ice plant may get a rate of 1 cent per kilowatt-hour, and usually no amount of explanation will convince the man paying a rate of 10 cents that he is not being robbed. On the other hand, the man paying the 1-cent rate knows that he is getting only a fair rate and the power company is certain both of them are being treated fairly. Because of the confusion that exists in the minds of the consumers many power companies, especially those supplying lighting to many eastern cities, do not encourage the use of electricity for power, because they believe the lighting consumers will think they should have the same rates, or at least lower rates than are warranted. As a matter of fact, a thorough understanding on the part of the consumer and the offering of the electric service for all purposes, especially for power, will result not only in some reduction in rates to the lighting consumers, but what is much more important, the use of electricity for power purposes will stimulate other industries and these will, of course, make the community more prosperous. A prosperous community or individual is never burdened by the lighting bill, as it is insignificant when measured in terms of the service received and the general benefits derived by the community when it has an ample power supply available and used for all purposes.

Electricity for lighting and power purposes cannot be stored in any large quantities, therefore the plant must at each instant generate the total supply. The lighting consumer must, therefore, have available all day the possibility of instant service, but he may only use the service to produce revenue for the company a few hours each evening. This is the usual explanation given for the higher rates charged for lighting, that is, that the lighting consumer uses the light only a few hours per day, whereas the power user's service extends over the larger part of the day, and also the power consumer uses a much greater quantity. The revenue obtained from a consumer having a 100-h.p. motor may be equal to that obtained from a hundred or two hundred lighting consumers, and herein lies the crux of the entire matter, but the consumer does not see it, so we will try another way of explanation.

If, for example, the total of investment and operating expense to serve all the lighting consumers is equal to the total of investment and operating expense to serve all the power consumers, then plainly the revenue derived from each class of service must be the same in order that each may bear its fair share of the expense of the service. In the average up-to-date light and power system the total energy, generally expressed in kilowatt-hours, consumed by the lighting consumers is very much less than the kilowatt-hours consumed by the power consumers. If the power consumers use five times as much as the lighting consumers, then, on the assumption that it costs as much to serve all the lighting consumers as it does all the power consumers, the rate per kilowatt-hour charged the lighting consumers must be five times as large as the rate charged the power consumer. Generally, however, especially when water power is available, and on account of the large cost of distribution, the cost of serving the lighting consumers is greater than the cost of serving the power consumers, so that a greater difference than five to one must exist in the rates for service.

To use a parallel case for illustration, let us take the railroad service and compare the cost of hauling passengers and freight. Transcontinental freight is hauled by the railroads from the East to California at about $1.50 per 100 lb. To haul 300 lb., or about the weight to be hauled when one passenger and his baggage is carried, will give the railroad a revenue of $4.50. The revenue derived, however, for hauling a single passenger over this distance is more than ten times this amount, and yet the passenger only pays his fair share of the expense. Again, local freight is hauled at 1 cent and 2 cents per ton-mile, whereas the passenger pays 2 to 3 cents per passenger-mile; that is, the passenger pays more to be hauled one mile than is charged to haul a ton of freight one mile. The classes of service and the basis of charge are here entirely different, hence there is no confusion in the minds of the public.

Again, a railroad devotes, let us say for simplicity of explanation, one half the railroad investment and one half the operating costs to freight service and the other half to passenger service. In that case plainly the freight revenue and passenger revenue must be equal in order to be equitable. But the railroad may haul 1,000,000,000 tons of freight at an average return of 1 cent per ton-mile, producing $10,000,000 in earnings, and only carry 400,000,000 passengers one mile. Clearly, in order to produce the same revenue from the passenger as from the freight service, it must receive an average rate of 2½ cents per passenger-mile. On a ton-mile basis in the illustration the passenger pays about twenty times the rate per ton-mile paid for the freight service. And yet there is no confusion in the minds of the public in this instance, mainly because the same unit of charge is not used. If the railroads attempted to put the passenger business on the same basis as the freight, that is, weigh the passenger and charge so much per ton-mile, as in the case of freight, the public would think it was being robbed, but as a matter of fact, the rates are equitable.

As a matter of equity the passenger-mile rate for service is proper and logical and so is the ton-mile rate for freight. Passenger business is a personal service and paid for on a different unit basis and not on a ton-mile basis as freight is hauled.

Now a similar difference exists in the lighting and power service which brings to the minds of the public the confusion as to the reason for the difference in rates for lighting and power.

Plainly if, for illustration as before, we assume that the investment cost and operation cost of supplying energy for power consumers are the same as the cost for supplying the lighting consumers, it follows that the revenue derived from the two classes of business should be the same. But if the total energy consumed by the power consumers is five times that used by the lighting consumers, it is evident that the average rate charged per kilowatt-hour for lighting must be five times the average rate charged for power. That is, if the average rate for power is 1 cent per kilowatt-hour, the average rate for lighting must be 5 cents per kilowatt-hour. If the company sells 500,000,000 kw-hr. for power at an average rate of 1 cent, it will receive $5,000,000 in revenue. But if the amount of energy supplied for lighting is only 100,000,000 kw-hr. the charge must be 5 cents per kilowatt-hour to produce the same revenue.

Always, however, on account of the cost of distribution, the cost of the lighting service is much greater than the cost of the power service, and generally, therefore, we find the lighting rates about ten times the rates for power service. The total investment in the given case, for illustration, may be divided as follows:

Investment for power consumers	$15,000,000
" " lighting consumers, to substations	15,000,000
" " lighting consumers, for distribution	15,000,000

And the earnings necessary so that each may pay its fair share may be as follows:

From power consumers	$3,000,000
From lighting consumers, to substations	$3,000,000
From lighting consumers, for distribution	$3,000,000
Total to be earned	$9,000,000

The power consumers may use	400,000,000 kw-hr.
The lighting consumers may use	100,000,000 "

Fair rates would then be:

For power consumers, charges to substations .... $\frac{300,000,000 \text{ cents}}{400,000,000} = 0.75$ cent per kw-hr.

For lighting consumers, charges to substations......... $\frac{300,000,000 \text{ cents}}{100,000,000} = 3$ cents per kw-hr.

For lighting consumers, for distribution............... $\frac{300,000,000 \text{ cents}}{100,000,000} = 3$ cents per kw-hr.

This would make the total average rate to the lighting consumer 6 cents per kilowatt-hour, and the total average rate to the power consumer $\frac{3}{4}$ cent per kilowatt-hour. If the kilowatt-hours consumed for lighting are 150,000,000, the rate to the substation is 2 cents per kilowatt-hour, and the total rate 4 cents.

In the above explanation, which the consumer can understand, there is no use of the terms diversity factor and load factor. It puts lighting consumers in one class and power consumers in another, and determines average class rates from the cost of giving service and the amount of energy used by each class of consumer.

It is seen, therefore, that the lighting consumer's rate is much higher than the rate to the power consumer because:

(1st) The investment and cost of operation to serve the lighting consumer are greater than the investment and cost of operation to serve the power consumer, and

(2nd) Much more important, the total energy consumed by the power consumers is much greater than that used by the lighting consumers *for the same peak demand.*

The confusion that exists in the case of the lighting rates comes from charging for the same unit of service. In the freight and passenger rates there is a natural difference in the method of charging, hence there is no confusion. In the lighting and power business there is no such natural method of charging a different unit rate. It has been occasionally urged to charge the power user on a sliding scale of charges, starting at the same rate charged the lighting consumer. If the power consumer made the same demands as the lighting consumer, his rate and total charge would be the same as the lighting consumer up to the substation. The scale of rates charged the power consumer would drop rapidly, in excess of this amount, and his average rate could be approximately the same as it would be under the ordinary power rate schedule. But there is objection to this on the part of the power consumer. It is believed, however, that until some form of schedule of rates or class rates is devised which strikes all consumers alike, there will be difficulty in educating the public as to the reason for the difference in the rates. It is believed that equitable "class rates" as herein described will remove the present misunderstanding.

That low average power rates are necessary for low cost of lighting service cannot be questioned, just as low freight rates are necessary in order to obtain low passenger rates. If an attempt were made, for example, to raise the freight rates per ton to nearly equal the passenger rates, there would be no freight, no business, and consequently no money and no passengers.

In the same way, low rates for power service are not only equitable, but absolutely necessary in these times in order to promote the industries of the communities. If we should attempt to raise the rates to the power consumers, the lighting consumers would soon disappear, as business would become stagnant, because in this modern day general power and low rates are necessary in order to make a prosperous community.

Similarly, the reason for the difference in the " class rates " for commercial and residence lighting may be explained. For example, in order that the commercial and residence lighting may pay equitable proportions, let

Power earnings necessary for commercial lighting = $1,000,000
" " " " residence " . = 2,000,000
Distribution " " " commercial " . = 1,000,000
" " " " residence " . = 2,000,000
Suppose commercial consumers use 50,000,000 kw-hr. per year,
and residence consumers use 50,000,000 " " "
From this we obtain:
Average power charge, commercial....... = 2 cents per kw-hr.
Average power charge, residence......... = 4 " " "
Average distribution charge, commercial . = 2 " " "
Average distribution charge, residence.... = 4 " " "
Total average charge, commercial lighting . = 4 " " "
Total average charge, residence lighting. = 8 " " "

It will be noted that if the energy consumption is doubled the rate will be halved, if the total cost remains the same. There will be further differences between large and small commercial residence business, but these can be taken into account in a sliding scale. In the same way there will be reason for class rates for certain kinds of power business, depending largely on size of plant and the hours during which power is consumed, and a sliding scale of rates for each class of business.

The general method used in determining class rates for a system is as follows: Divide the total amount of money to be earned by the power and light class by the sum of the peak demands of the two classes. This gives the demand charge per kw. Multiply this demand charge by the peak demand of the class. This gives the total revenue to be earned by the class. Divide this revenue by the kilowatt-hours consumed by the class and we obtain the *average class rate* per kw-hr. An example of this will be given later, and in Fig. 1.

The present general method of determining electric lighting rates is to begin at the consumer and add the cost of reading meter, billing, collecting, etc., to the distribution cost and to this add the cost of power. This is equivalent to what the railroads would do if they tried to determine passenger rates between two points by adding the cost of the sale of a ticket to the cost of the oil required to haul the passenger and to this then add the cost of passenger equipment and proportionate cost of the railroad system between the two points. This method is necessarily subject to errors and tends only to confuse, as it concentrates attention on the infinitesimal items.

Why is it not better to take all the passenger business and determine average class passenger rates for the entire system, by taking the entire cost of doing all the railroad business and dividing this cost among the various classes in proportion to the use of the facilities and operating expenses of the different classes? Similarly, much more accurate and satisfactory results can, I believe, be obtained in determining electric rates by proportioning the earnings necessary to support the entire property between the different classes. The total earnings necessary to support the property can be determined, and the proportionate use of the facilities can be readily determined accurately enough for practical purposes. With these facts and the kilowatt-hour consumption of the different classes known, very fair class rates may be determined. In no other way can I see any satisfactory solution of the rate question, so that the business in all its departments may be built up to the best advantage of all the classes of consumers.

The present method is too much like trying to arrive at the cost of raising chickens by "counting them before they are hatched." A safer and better way is to take the actual results of some chicken ranches over a long enough period of years, so that instead of trying to figure the uncertainties and hazards of each item of the business, they are all summed in the balance sheet.

As we have seen, the cost of railroad service per passenger-mile bears only the remotest relation to the cost per ton-mile for freight, and in a degree the same difference exists between residence lighting and power. Also, the cost of hauling a car of nails is about the same as a car of transformers, but the rate on nails is and must be lower for two reasons, (1) there are more nails hauled, and (2) the value of the service is greater in hauling a car of transformers than in hauling a car of nails. To get the nail business at all, the nails must be hauled at a lower rate, and the fact that they bring in revenue in excess of the cost, makes it possible to haul the transformers at a lower rate than could be done if the rates on nails were raised.

Similarly, the cost of electric lighting bears only the remotest relation to the cost of supplying power. Again, the cost of supplying power service to a sawmill or a planing mill must be lower than for supplying another class of factory. First, because the planing mill man insists that if he gives us his power load he must make some profit, and we must therefore furnish him cheap power or we do not get his business at all. Second, if we do not get the planing-mill business, although it may not be as profitable as some other lines of business, we must increase the rates to the other users in order to make up the revenue necessary to support the property. Hence it is generally to the advantage of the other power consumers that the company take on low class power consumers, if this business pays more than the operating expense and serves to reduce rates in general. Three things must be kept in mind regarding any new business:

First—Some profit must be made for the consumer in order to get the business.

Second—Some profit must be made for the company.

Third—The tendency of the business taken on must be such as to cause a general lowering in rates as volume of business increases.

The early electric companies were organized to supply lighting. It was soon recognized that the plant could take on day power, and increase the net revenue, which meant of course that the investment was more efficiently used. As a result of the power business the rates for lighting have been materially reduced.

If some industry, for example, could be established to use the power service from say 12 p.m. to 7 a.m., very low rates indeed could be made to get this business. Any revenue added over operating expense would be so much revenue which could be subtracted from the charges to other consumers, hence, even though this business had to be taken at less than one-half cent per kilowatt-hour, it would, from the standpoint of all consumers, be very profitable business for the company, as the earnings would be largely added to the surplus.

The initiation of the low-price night letters by the telegraph companies is an example of additions to the volume of business with the same equipment, tending to reduce the cost of telegraphic service generally.

An example will probably make this plain, although it is quite elementary to the managers of utility properties. Assume that we have installed a waterpower plant (no steam reserve) having a normal capacity of 10,000 kw., and that it has cost, including transmission line and substation, $2,500,000. To make the example as simple as possible we will assume that the company contracts to supply the lighting of a city wholesale, so that the company shall earn 8 per cent on its investment in addition to the operation, depreciation and maintenance charges, etc. The total annual consumption is, say, 15,000,000 kw-hr. The consumer agrees to pay 10 per cent in excess of the rate determined from costs in order to have a margin of safety.

Then for the cost of service we have:

Interest		8 per cent	= $200,000
Depreciation	1.5 per cent		
Maintenance	1.5 "		
Taxes and Insurance	1.0 "	4 "	100,000
Total		12 per cent	$300,000
Operation and management			150,000
			$450,000

$$\text{Cost per kw-hr.} = \frac{45{,}000{,}000 \text{ cents}}{15{,}000{,}000 \text{ kw-hr.}} = 3 \text{ cents per kw-hr.}$$

Adding 10 per cent for safety margin = 3.3 " " "

There is a daytime power load of 45,000,000 kw-hr. annually, available in the same town, that can be supplied from the same substation, with the same power plant and transmission system. However, in order to make a rate attractive enough to get the power load, it is agreed that the power consumer shall pay only 6 per cent on one-half the investment which necessitates that the lighting consumer pay 10 per cent. Each consumer agrees to pay 10 per cent in excess of the rate determined from absolute costs in order to have a margin of safety. The costs then chargeable to the lighting consumer will be:

Interest		10 per cent of one-half investment,	$125,000
Depreciation	1.5 per cent		
Maintenance	1.5 "		
Taxes, ins., etc.	1.0 "	4 " " " "	50,000
Total		14 "	$175,000
One-half operation and management cost			75,000
Total charge to lighting consumer			$250,000

$$\text{Cost per kw-hr.} = \frac{25{,}000{,}000 \text{ cents}}{15{,}000{,}000 \text{ kw-hr.}} = 1.66 \text{ cent per kw-hr.}$$

With 10 per cent added as margin of safety, rate = 1.836 cent per kw-hr.

The result to the lighting consumer is to reduce the rate from 3.3 cents to 1.836 cent per kw-hr., in spite of the fact that his interest rate has been increased from 8 per cent to 10 per cent.

The rate to the power consumer will be:

Interest.........		6 per cent of one-half investment	$75,000
Depreciation....	1.5 per cent		
Maintenance....	1.5 "		
Taxes and ins...	1.0 "	4 " " " "	50,000
Total.......		10 " " " "	$125,000
One-half operation and management cost.....................			75,000
			$200,000

Cost to power consumer per kw-hr. =

$$\frac{20{,}000{,}000 \text{ cents}}{45{,}000{,}000 \text{ kw-hr.}} = 0.444 \text{ cent per kw-hr.}$$

10 per cent added for safety margin gives rate = 0.4888 cent per kw-hr.

If now a consumer could be found to take the power from 12 p.m. to 6 a.m., when the other two consumers are not using it, a rate could be made by which his interest charge could be less than 6 per cent and still both the other consumers would benefit, as the operation charges would be increased very little.

Except for the cost of water storage, which should be apportioned to kw-hr. output, all charges on a water-power plant are demand charges and should be apportioned to peak demands of power and light classes.

Let us take now a typical case as applying to the above plant. The load curve in Fig. 1 may be assumed to represent such a case. Here we have the peak demand of the lighting class equal to 7500 kw. and the peak demand of the power class of 7300 kw. As a result the yearly charges of $450,000 are spread over 7300 + 7500 = 14,800 kw., instead of being spread over the 11,000 kw. of the total peak. As a result the yearly demand charges are reduced from

$$\frac{450{,}000}{11{,}000} = \$41 \text{ (practically) to } \frac{450{,}000}{14{,}800} = \$30.50$$

or the demand charges are reduced practically to 75 per cent of what they would be if there were only one class of consumers. This shows the advantage of the diversity factor 1.35. Now charge each class in proportion to class peak demand (see calculations in Fig. 1). As a result the light consumers pay 7500 × $30.50 = $228,750 of the total and the power consumers pay 7300 × $30.50 = $221,250 for power at the substation.

The average charge for lighting is

$$\frac{22{,}875{,}000 \text{ cents}}{15{,}000{,}000 \text{ kw-hr.}} = 1.52 \text{ cent, and adding 10 per cent}$$

gives 1.67 cent per kw-hr.

Similarly, the average power charge is

$$\frac{22{,}125{,}000 \text{ cents}}{45{,}000{,}000 \text{ kw-hr.}} = 0.49 \text{ cent, and adding 10 per cent gives}$$

0.539 cent per kw-hr.

Here we see the effect of the load factors; the lighting load factor being only 22.6 per cent, while the power load factor is 70.5 per cent. The average load factor is 62.5 per cent. Without the power consumer the rate to the lighting consumer would be

$$\frac{45{,}000{,}000 \text{ cents}}{15{,}000{,}000 \text{ kw-hr.}} = 3 \text{ cents, and adding 10 per cent gives 3.3}$$

cents; or, in other words, the lighting rate is reduced nearly one-half. Without the lighting consumer the power rate would

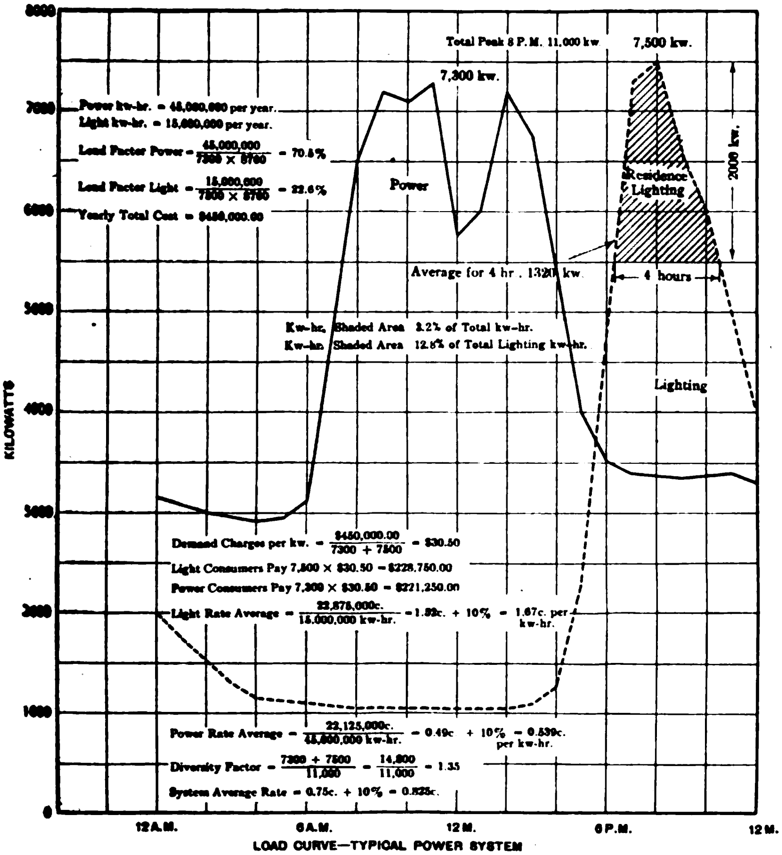

FIG. 1

be 1.1 cent. The mutual benefit is clearly shown by the example.

The following table shows the effect of the power load in reducing the charges to the lighting consumer.

Case	Total peak	Light peak	Power peak	Proportionate charges	
				Light	Power
A	10,000	7,500	2,500	75 per cent	25 per cent
B	10,000	7,500	5,000	60 "	40 "
C	10,000	7,500	7,500	50 "	50 "

The lighting consumer pays 100 per cent of all power charges if there are no other consumers, but by the addition of power consumers the lighting charges for power at the substation may be practically reduced one-half. From the substation to the consumer, of course, each class of consumer must bear its share of the additional expense.

There will be further differences of rates to different classes of lighting and power consumers, but the application of the principle is the same as in the above case. For the power consumers we start with the total amount to be earned by all the power consumers and by proportioning these charges according to the demands of the class, the total charge to the class is determined, and from the kilowatt-hours consumed by the class its average rate is determined. The method is believed to be scientific and can be made fair to all consumers under any circumstances.

In applying this method to a steam plant, all demand charges, that is, all plant investment and operation, would be proportioned to peak demand of power and light, and fuel and water only be charged as energy and proportioned to kilowatt-hour consumption of the two classes.

The following would be a somewhat logical arrangement of class rates:

Class	Kind of service
1	Residence lighting
2	Commercial lighting, electric heating, etc.
3	Agricultural power
4	Industrial power
5	Power (24-hour).
6	Power (off-peak).
7	Power (10 p.m. to 6 a.m.)

It is not intended in this paper to go into the question of the proper rates under each class, but rather to limit the paper to a discussion of the general principles of class rates in such a way as to make clear to the consumer and the investor the necessity and justification for such rates, to the end that there will be a better understanding of the electrical business as an extremely important part of the economic development of any community.

The principle at the bottom of all rates is to make the plant earn all it can during every hour of the day so that the burden of the investment may be distributed. That is, to make the rates within the reach of the lighting consumer, it is necessary to make low power rates in order to distribute the charges over as many kilowatt-hours as possible.

The same principles apply to nearly all public utilities. As a precedent for rates of this kind we have the railroad, telegraph, express, and postal rates.

Generally the power service requires a steam reserve plant for service insurance, and usually, during periods of low water, storage water must be used and the steam reserve plant must be operated part of the time. It is evident that the cost of oil for the steam reserve and the cost of water storage, both representing energy, should be apportioned to the kilowatt-hours consumed by each class. In general the total charges for power delivered to substations are made up in two items:

First: Demand charges, which should include interest, maintenance, depreciation, operation and management.

Second: Energy charges, which should include oil and water for steam reserve plant and the cost of storage water, as these are the only items that should be proportioned to kilowatt-hours output.

The total charges above would be divided for light and power classes into demand and energy charges, as follows:

Light class demand charge =

$$\frac{\text{total demand charge} \times \text{light peak}}{\text{light peak} + \text{power peak}}$$

Power class demand charge =

$$\frac{\text{total demand charge} \times \text{power peak}}{\text{light peak} + \text{power peak}}$$

Light energy charge =

$$\frac{\text{total energy charge} \times \text{light kw-hr.}}{\text{light kw-hr.} + \text{power kw-hr.}}$$

Power energy charge =

$$\frac{\text{total energy charge} \times \text{power kw-hr.}}{\text{light kw-hr.} + \text{power kw-hr.}}$$

Without taking into account the fact that it is the lighting consumer who demands most the service insurance of the steam reserve and who uses the steam reserve inefficiently because it is only used a few hours per day, let us make a few general figures to see what the steam reserve adds to the energy costs of the two classes over those shown by the example in Fig. 1.

Let us assume that the low-water period is three months, or one quarter of the total kilowatt-hours must be supplied by steam power or its equivalent storage water. Let us assume the cost of oil and water for the steam reserve plant a· 0.4 cent per kw-hr. and allow the same per kw-hr. for the storage water. Then 15,000,000 kw-hr., or one quarter of the total, must come from storage water or steam power, making a total of $60,000 per year. This will add 0.1 cent per kw-hr. to the total and to each class of consumers' rates, the final rate then being 1.77 cent for the lighting and 0.639 cent for the power.

Adding this 0.1 cent per kw-hr., the *average* rate for power at the substation in the above example is:

$\frac{45{,}000{,}000 \text{ cents}}{60{,}000{,}000} + 0.1 \text{ cent} = 0.75 + 0.1 = 0.85$ cent, and adding the 10 per cent for margin of safety, the average rate is 0.935 cent per kw-hr. The average fair lighting rate is, however, 1.77 and the average fair power rate is 0.639 cent.

It is seen, therefore, that the lighting rate is nearly double the average, and the power rate about one-third less than the average rate. It is fallacious, therefore, to apply the average rate for a system to the different classes of consumers, or to different districts or towns. Each class, town or district gets the advantage of the diversity factor (usually about 1.3) for the system, but the rates for the class, town or district should be determined by the method here used.

If a town, for example, has a lighting peak of 100 kw., the lighting consumers in that town must pay $\frac{100}{7500}$ of the total paid by all the lighting consumers on the system. The rate per kilowatt-hour for the town will be determined by dividing the total to be paid by the kilowatt-hours consumed, and therefore the rate per kilowatt-hour depends on the consumers themselves, that is, on how much they consume.

As a check on the above average lighting cost of power, let us see what the average cost of power for the residence lighting would be if supplied by a steam plant. The residence lighting may be taken to extend four hours per day and the following figures, then, are taken from Fig. 1.

Peak load steam plant	2,000 kw.	
Average load " " 4 hours	1,320 "	
Average load " " 24 hours	220 "	
Kw-hr. per year, 220 × 8760 =	1,927,200	
Cost of plant	$200,000.00	
Interest	8 per cent	
Maintenance and depreciation	4.5 " "	
Operation and management, etc.	2.5 " "	
Total cost	15 per cent =	$30,000.00
Energy cost for fuel and water only, 0.5 cent. per kw-hr. = 1,927,200 × 0.005 =		9,636.00
Total cost per year		$39,636.00

$$\text{Cost per kw-hr.} = \frac{3{,}963{,}600 \text{ cents}}{1{,}927{,}200 \text{ kw-hr.}} = 2.05 \text{ cents}$$

Demand cost	1.55 cent
Energy cost	0.50
	2.05 cents

The cost of supplying power, therefore, to the residence lighting, will probably average 2 cents per kw-hr. A sliding scale would take care of differences in the individual lighting rate.

The steam plant capacity to take care of the four-hour peak is 2000 kw. or 20 per cent of the entire plant. The kilowatt-hours output is, however, only 3.2 per cent of the total output and only 12.8 per cent of the total lighting load. This brings out clearly the reason for the high unit cost for the consumer taking only a small amount of energy for lighting for about four hours per day.

It is generally known that the railroads prefer the freight to the passenger business, but it is not so generally known that the power companies, at least those having water power, prefer power business to lighting business. And again, commercial business is generally more attractive than residence business. This is evidenced by the fact that certain companies confine their operations to the commercial districts. One of the reasons for this condition is the large amount of capital necessary to serve the small consumer.

Thus it is seen that the attractiveness of the business really varies almost inversely as the rate per kilowatt-hour charged, which is directly contrary to public opinion.

In practise, the difficulty of determining average equitable class rates need not be serious. The most important item is the amount of power consumed by each class, and this can be determined; the item of the maximum demand of each class or the proportionate cost to be charged to each class of business cannot be so accurately determined, but if an error of 10 per cent were made in the example of power and light cost to sub-stations, it would, say, increase the power rates from 0.75 to 0.825 cent, and reduce the lighting rates from 6 to 5.7 cents. An error of 10 per cent in the annual cost of operation would mean an error of $300,000 added to one class and subtracted from the other. The total amount of revenue to be earned can readily be determined, and, if we get the class rates within 10 per cent of the correct amount, there should be no serious complaint.

It is a cut-and-try method, but past practise has already largely determined class rates. The main thing is to have class rates that will develop the business and that will give consumers the right idea of the cost of their class of business, and not have the lighting consumer confused by having his mind on the power rate for an entirely different class of business and supposing that this rate should apply to him.

(5) To get the best results for the company and the consumer, some plan must ultimately be worked out to make an incentive for the company to reduce the cost of the service. At the present time a company may have an obsolete and inefficient engine plant in operation. This stands on the books at, say, $50,000. If this unit is replaced by a modern turbine costing, say, $100,000, the company must wipe off from the books the old engine plant. As a result of the new turbine, the cost of the service is decreased, but generally the effect of this on the company is to have its rates cut. The company has then replaced an old engine by a modern one giving better service, and as a result it has its rates reduced. Of course this state of

affairs does not tend to give the lowest cost of the service, as there is no incentive for the company to improve and reduce the cost of the service. To the credit of most of the large companies it can be said, however, that they have made improvements in spite of this handicap, but the small company generally cannot finance the new improvements.

Again, a community is to be served with electric power. Two plans are feasible, one a local steam turbine plant, the other electric power developed in the mountains and brought to the community by many miles of transmission. The steam power development will cost about one-half the hydroelectric, but the cost of service to the community will be higher if steam power is used. In either case, under present conditions, earnings on the investment are the same percentage. Why, then, go to the mountains and work several years acquiring property, making surveys, getting rights-of-way from a thousand or more owners, if the result to the promoting company is only the additional burden of raising the added amount of capital required—and the consumer gets lower rates?

Of course, under the conditions, there will be only a limited amount of water power developed. To make the water power development attractive there must be an allowance made to produce the incentive to make the water power development. This can be done by an allowance for value of water rights or by allowing a higher rate of return on the investment in water power and the electric transmission of this power to the community.

Economy in construction and operation is much more important than ordinarily assumed, and a company able to get these results should be encouraged. A high-class organization is as necessary as a high-class power system in order to give efficient service. The standard of the business must, therefore, be such as to attract high-class men to the service, and the ability of the company to obtain money must be such as to make it the aggressor in making economies and in obtaining new business.

It costs money to get together a high-class organization and it costs money and energy to keep it together and working efficiently. Different organizations may easily make a difference of 25 to 75 per cent in the cost of construction, and a difference of 5 to 25 per cent in the cost of operation.

It should also be remembered that economy of financing is one of the important elements in low cost of operation. If, through lack of confidence on the part of investors, money cannot be had on reasonable terms, the cost of the service must increase.

The relative value of men to society cannot be expressed as any function of their length, breadth, and thickness, but their value is a function of the saneness and fertility of their imagination, of the confidence inspired by their honesty and ability, and of the results accomplished by their energy and enthusiasm. Similarly, the value of a utility to a community is not capable of full determination by measurement of physical dimensions of structures and the classification of materials, and the fixing of unit prices, and the use of an adding machine. The highest dam or the largest area of reservoir, the longest canal or the longest transmission, do not necessarily give the best power system. The cost of a thing does not measure its value. The boy who spends most money at college does not get the most education. Cashable ideas are not purchased by the pound or cubic yard.

The value of a system is measured by what it does when compared with some other system, and by what the system does for the general good of the community. And what the system does for the general good depends on the ability and honesty of those directing the work, and on the imagination, ability, confidence and the enthusiasm with which the work is done.

To promote the eagerness and ability on the part of the consumer and the company, which is necessary for the best interests of the business, we see, therefore, that ability, brains, confidence, and large experience are necessary, and we cannot get the same results by replacing these with ambition, brag, conceit, and by jumping at conclusions derived from wrong premises and without the test of experience.

All of which, and more, is expressed by the axiom at the beginning of this paper, " The best control of a public utility is that which develops an eagerness and ability on the part of the company to furnish the service, and an equal eagerness and ability on the part of the consumer to purchase the service."

CONCLUSION

It is believed that the success of the electric power business depends upon developing a diversified load. To obtain a diversified load it is necessary to have "class rates," in order that the power business may be developed parallel with the lighting.

Class rates, as determined by the method described in this paper, it is believed, are equitable to all consumers and will result in the lowest rates to all consumers as business is developed.

The eagerness and ability which it is desirable to create on the part of the public utility company and the consumer, then, primarily depend upon two things:

(1) Liberal rates of return on investment so that the companies will make extensions and economies.

(2) Class rates determined by the method herein outlined, applied to develop all the possibilities of the business.

To be presented at the 303rd meeting of the American Institute of Electrical Engineers, New York, January 8, 1915.

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(*Subject to final revision for the Transactions.*)

THEORETICAL INVESTIGATION OF ELECTRIC TRANSMISSION SYSTEMS UNDER SHORT CIRCUIT CONDITIONS

BY I. W. GROSS

ABSTRACT OF PAPER

The following features of a transmission system under short-circuit conditions are discussed:

1. Mechanical forces between the phases of three-conductor, three-phase cables when carrying short-circuit current; also the forces between busbars are investigated.
2. The heating of the conductors of the cable from the instant of short circuit to a time 0.8 seconds later is traced analytically, during the transient state of the current, and typical computed heating curves are presented.
3. The effectiveness of the method of placing reactors between generator terminals and the bus from which power is taken, and additional reactors between generators and an auxiliary synchronizing bus, is analyzed.
4. This scheme is compared with the present well-recognized schemes of feeder and busbar reactors.

THE rapid growth of central stations in recent years with the constantly increasing power concentrated on one set of busbars has made necessary some method of protecting the system as a whole, and also its various parts, in case of abnormal conditions on the line. Reactance, which formerly was stringently avoided in central station electrical apparatus, is now being almost universally required in the apparatus itself, and in many cases additional reactance is supplied by reactors external to the electrical units.

In applying these reactors to central station design, much attention has been given, and several well-recognized schemes have been worked out and are now in operation.

The parts of the high-tension system for which protection must be furnished under short-circuit conditions are as follows:

1. Oil switches against absolute failure.
2. Generators, transformers, busbars and underground cables against mechanical forces.
3. All apparatus against overheating
4. The system as a whole against complete shut-down.

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A system designed to provide protection against any three of the above cannot be considered ideal if it fails in the fourth; and it is only by limiting the short-circuit current to such a value in different parts of the circuit as to eliminate the above controlling factors that the use of reactance can be regarded as fully effective.

ULTIMATE OIL SWITCH CAPACITY

In the case of oil switch breaking capacity, it is possible at the present time to obtain a guarantee for switches to clear any trouble on an 11,000-volt, three-phase system with a running capacity of 70,000 kv-a. and a reactance of 10 per cent; that is, a short-circuit current of 36,800 r.m.s. amperes. It is, therefore, assumed from the foregoing guarantee, that any 11,000-volt system, where the short-circuit current does not exceed 36,800 amperes, will experience no inherent difficulty from oil switch trouble.

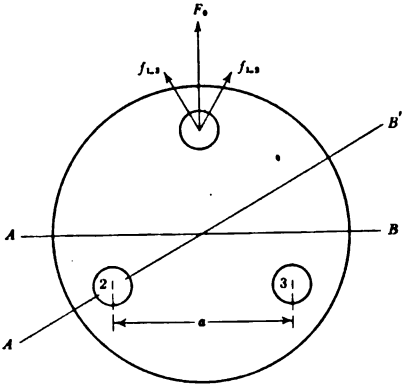


FIG. 1

MECHANICAL FORCES IN ELECTRICAL APPARATUS

This phase of the problem has been given careful attention of late, especially in generators, with the result that generators are now being built with such mechanical rigidity that manufacturers maintain they will safely withstand the mechanical forces arising from dead short-circuit across their own terminals.

Modern transformers, likewise, are being more substantially built, so that it is unlikely that mechanical rupture will occur in them before some other limiting features of the system are exceeded.

Underground cables and busbars are subject to even heavier strains than the generators themselves, and an analysis of these stresses is here given.

FORCES BETWEEN CONDUCTORS OF THREE-PHASE CABLE

First, take a three-conductor cable, as shown in Fig. 1, with all three conductors equally spaced, and assume all three legs simultaneously short-circuited, and the r. m. s. current equal in each phase. Then the force tending to repel any conductor in a direction at right angles to a plane passing through the other two may be computed as follows:

Let the currents in all three phases, 1, 2 and 3, be sinusoidal. In Fig. 1, let $i_1 = I_m \sin \omega t$ = instantaneous current in phase 1.

$$i_2 = I_m \sin\left(\omega t + \frac{2\pi}{3}\right)$$

$$i_3 = I_m \sin\left(\omega t + \frac{4\pi}{3}\right)$$

I_m = maximum value of sine wave.

Then f_{1-3} = instantaneous force between conductors 1 and 3.

f_{1-2} = " " " " 1 " 2.

f_0 = " " on conductor 1 perpendicular to plane $A.B.$

$f_0 = (f_{1-3} + f_{1-2}) \cos 30°$

$f_{1-3} = k\, i_1 i_3 / a.$

$f_{1-2} = k_1\, i_1 i_2 / a.$

k = numerical constant

F_0 = average force on conductor 1 perpendicular to plane $A\ B$.

$$F_0 = \int_0^{\frac{1}{n}} d f_0 = \frac{k\, n\sqrt{3}}{2a} \int_0^{\frac{1}{n}} (i_1 i_3 + i_1 i_2)\, dt$$

$$= -\frac{\sqrt{3}}{2\ a} k\, I^2$$

I = r. m. s. value of sine wave $= \dfrac{I_m}{\sqrt{2}}$

n = cycles per second.

$\omega = 2\pi n.$

If F_0 is in lb. per foot of cable and I in amperes

$k = 5.39 \times 10,^{-7}$ a being in inches.

$$\text{Hence } F_0 = -\frac{4.67\, I^2\, 10^{-7}}{a\ (\text{inches})} \text{ lb. per foot} \qquad (1)$$

The negative sign appearing in the expression for the average force, F_0, means that the conductors under study are subject to repulsion. Thus, in a paper-insulated, lead-covered cable,

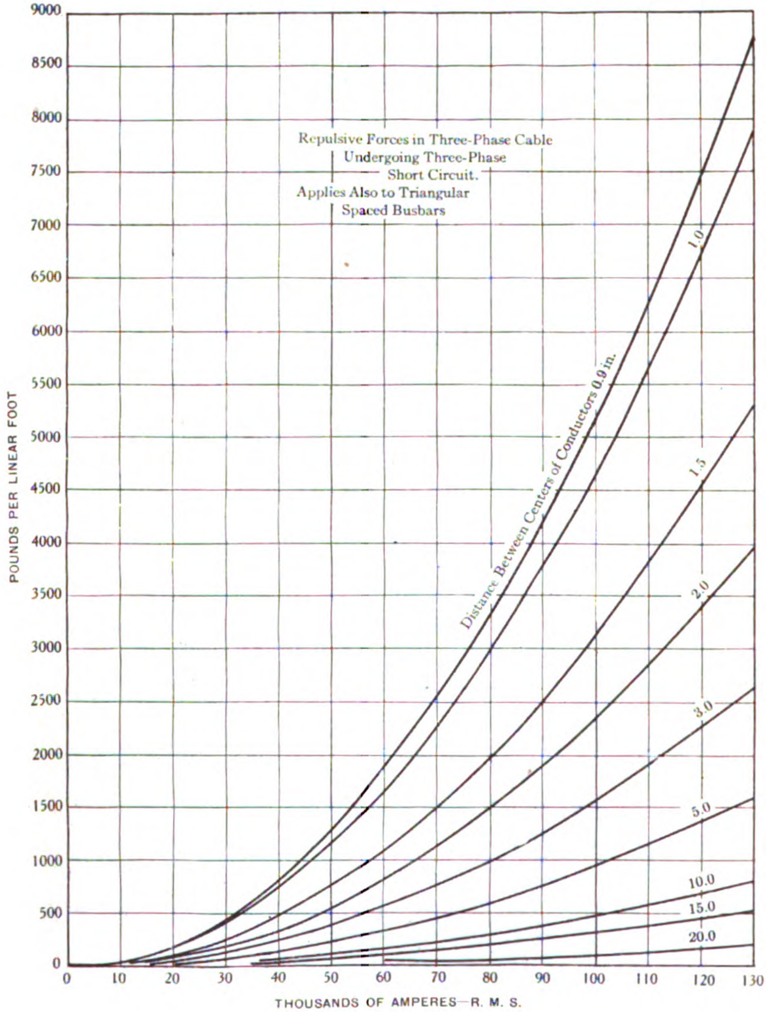


Fig. 2

the force is exerted on the over-all wrapping around all three conductors and also on the lead sheath; and the tensile strength of the paper and lead must be sufficient to withstand the stress thus placed upon them.

On busbars this force tends to throw the busbar away from the center of the equilateral triangle (of which each busbar is assumed to form one apex) and produces tension or compression on the busbar clamps, depending on the location of the insulators.

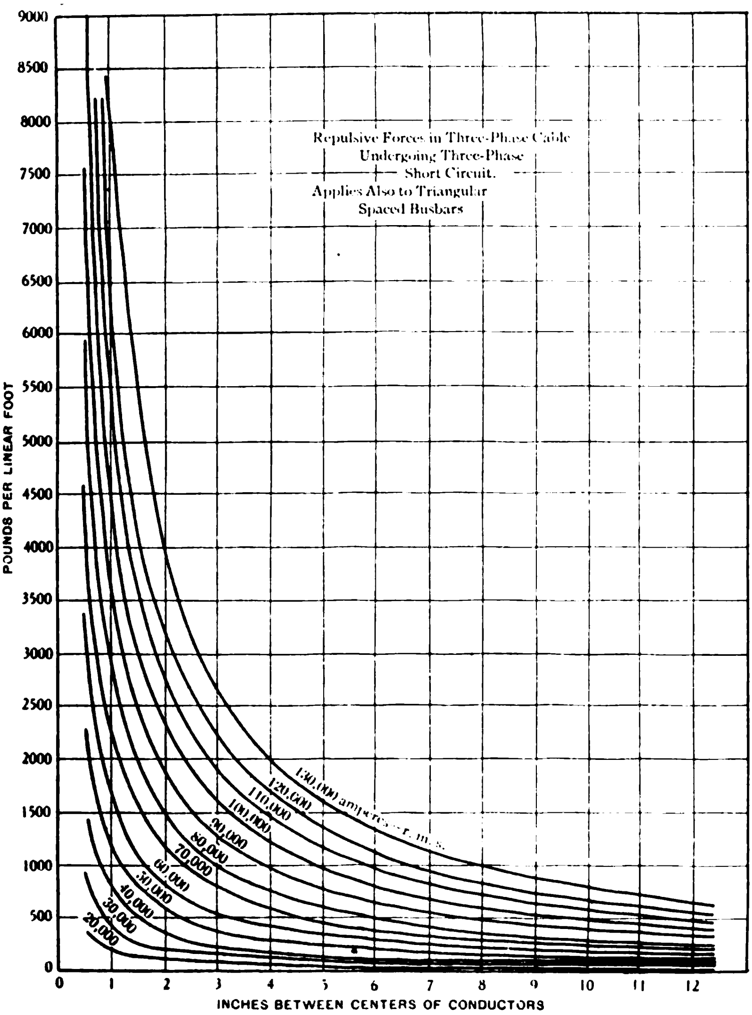


Fig. 3

From equation (1) the curves in Figs. 2 and 3 have been computed. The curve in Fig. 2 marked " 0.9 inches between conductors " represents the varying average force on one conductor of a three-conductor 3/0 B. & S. paper-insulated lead-covered

11,000-volt cable. For this particular cable, the insulation over each conductor was 7/32 inches, and the over-all paper wrapping was also 7/32 inches thick.

The rapid increase in force as the current rises is apparent from the following:

Current in 3/0 three-conductor cable	Force per foot of cable
20,000 amperes	208 pounds
40,000 "	832 "
70,000 "	2,550 "
100,000 "	5,200 "

At 20,000 amperes, the disruptive force is comparatively low, but rising in proportion to the square of the current it reaches a value of over one ton per foot at 70,000 amperes and over 2.5 tons at 100,000 amperes.

The busbars, due to the inherently greater spacing than the conductors of a cable, are subject to a much lower disruptive force per unit length, but on the other hand, since they are supported at only frequent intervals rather than continuously, as is a cable, the force on any support may become excessive. For example, with 20-inch triangular spacing, and 100,000 amperes flowing in each bus, the force on one phase is 100 lb. per foot. With supports nine feet apart, the force on any one support becomes nearly one-half a ton.

FORCES WITH SINGLE-PHASE SHORT-CIRCUIT

If the short-circuit is between only two line wires, instead of all three, then the average force per foot of line, for the same current value per wire as in a three-phase short-circuit, is 15.5 per cent greater. This is clear from the following analysis: Referring to Fig. 1, if the short-circuit takes place between phases 1 and 3, then the currents in 1 and 3 conductors are equal and

$$f_{1-3} = -kI^2_m \sin^2 \omega t.$$

$$F_0' = \int_0^{\frac{1}{n}} df_{1-3} = -\frac{k\,n}{a\,\omega} I^2_m \int_0^{\frac{1}{n}} \sin^2 \omega t \, d\,(\omega t) = \text{Average force on one conductor—single-phase short circuit}$$

$$= -\frac{k}{a}\; I^2_{r.m.s.}$$

$$\frac{F_0'\ (\text{single-phase})}{F_0\ (\text{three-phase})} = \frac{-K\,I^2}{a} \times \frac{-2a}{\sqrt{3}\,K I^2}$$

$$F_0' = F_0 \times 1.155 \tag{2}$$

If the forces in the curves of Figs. 2 and 3 are multiplied by 1.155, they are applicable to cases of single-phase short-circuit currents, also to direct currents. The plane of maximum stress in the cable is no longer *A B*, as indicated in Fig. 1, but the plane *A′ B′*, 30 degrees in advance of *A B*, and perpendicular to the line of centers of phase 1 and 3.

It should be emphasized, however, that a system designed to have a maximum r. m. s. short-circuit current of say 70,000 amperes per phase under three-phase short-circuit conditions will have less than 70,000 amperes on single-phase short-circuit, in fact, only 86.6 per cent of 70,000 amperes. And the maximum average mechanical force tending to tear the cable apart will likewise be only 86.6 per cent of the three-phase value.

To show the relation between three-phase and single phase short circuits take

E_{1-0} = voltage from line to neutral in a three-phase system.
E_{1-2} = line voltage.
Z = impedance per phase in short circuit path.
F = force tending to tear cable apart.

Three-Phase Short Circuit.

$$I_3 = \frac{E_{1-0}}{Z}$$

$$F_3 = -\frac{\sqrt{3}}{2a}\, k \left(\frac{E_{1-0}}{Z}\right)^2$$

Single-Phase Short Circuit.

$$I_1 = \frac{E_{1-2}}{2Z} = \left(\frac{\sqrt{3}}{2}\right)\frac{E_{1-0}}{Z} = 0.866\,\frac{E_{1-0}}{Z}$$

$$F_1 = \frac{-k}{a}\,\frac{3}{4}\left(\frac{E_{1-0}}{Z}\right)^2$$

$$\text{Hence } \frac{I_1}{I_3} = \frac{\sqrt{3}}{2}\,\frac{E_{1-0}}{Z}\,\frac{Z}{E_{1-0}}$$

$$I_1 = 0.866\, I_3 \tag{3}$$

$$\frac{F_1}{F_3} = \frac{+k}{a}\,\frac{3}{4}\left(\frac{E_{1-0}}{Z}\right)^2 \times \frac{2a}{\sqrt{3}\,k}\left(\frac{Z}{E_{1-0}}\right)^2$$

$$F_1 = 0.866\, F_3 \tag{4}$$

Thus, if the point of short circuit is fixed in the system, a short circuit between all three phases gives a current and a mechanical force each 15.5 per cent greater than does a single-phase short circuit. But if the point of short circuit is varied in the system so that the numerical value of the r. m. s. current is the same for three-phase as for single-phase short circuit, then the stresses set up in cables and busbar supports will be 15.5 greater for a single-phase than for a three-phase short circuit.

However, if the average stresses in conductors undergoing short-circuits are determined for the maximum r.m.s. current obtainable in a three-phase short circuit, then these forces cannot be exceeded for any condition of single-phase short circuit that may occur on that system.

FORCES ON BUSBARS SPACED IN A STRAIGHT LINE

If the bus bars all be in the same plane, the average force acting on the top or bottom bar is only 86.6 per cent as great as if the bars were spaced at the vertices of an equilateral triangle. This relation can be shown as follows, using the notation on page 27 and the diagram in Fig. 4.

The force on conductor 1 due to the currents in 2 and 3 equals

$$F_3' = \int_0^{\frac{1}{n}} f_{1-2} + f_{1-3}$$

$$f_{1-2} = \frac{k}{A} i_1 i_2$$

$$f_{1-3} = \frac{k}{A} i_1 i_3$$

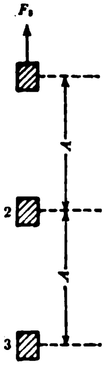


FIG. 4

$$F_3' = \frac{n\ k\ I_m^2}{\omega A} \int_0^{\frac{1}{n}} \left(-\frac{3}{4} \sin^2 \omega t + \frac{\sqrt{3}}{4} \sin \omega t \cos \omega t \right) d\,\omega t$$

$$= -\frac{3}{4}\ \frac{k\ I^2_{r.m.s.}}{A}$$

$$F_3' = \frac{-4.04\ I^2 \times 10^{-7}}{A}\ \text{lb. per foot} \qquad (5)$$

(I in r. m. s. amperes—A in inches).

From equation (**1**)

$$F_0 = -\frac{4.67\, I^2 \times 10^{-7}}{a}$$ force on conductor at vertex of equilateral triangle.

or

$$\frac{F_3'}{F_0} = 0.866 \qquad (\mathbf{6})$$

That is, for a given minimum spacing, A, between the nearest two conductors, the straight line arrangement gives only 86.6 per cent of the stress on busbar supports which exists with equilateral triangular spacing.

From equation (**5**), the curves in Fig. 5 are plotted. These are similar to those in Fig. 3, merely being reduced by the factor 0.866, as is indicated in equation (**6**). They represent the force acting on either the top or bottom busbar with the arrangement of buses shown in Fig. 4. This force acts outwardly in both cases that is, in the plane of all three buses and away from bus No. 2.

From the foregoing analysis, it is clear that if mechanical force in the conductors undergoing short circuit is the limiting feature of a system, in three-phase cables this may be controlled by reducing the possible current flow under short-circuit by use of reactors; or increasing the size of the cable and thus increase the spacing of the conductors. With busbars, the mechanical forces may also be decreased in the same way as above described for cables, and they may be further reduced by the method of arrangement, that is by placing the bars in the same plane rather than at the vertices of an equilateral triangle.

HEATING OF CABLES DURING PERIOD OF SHORT-CIRCUIT

Typical Short-circuit Current Waves. When short-circuit conditions occur on an alternating-current power system, the current does not drop into its steady state at once, but rather starts at a given value, depending on the instant of short-circuit, and falls off gradually until the induced voltage in the generators has been reduced by armature reaction to that value which will maintain in the short-circuit path the current which will keep the net generator field at the proper value for sustained short-circuit conditions.

Two typical curves of short-circuit current in generators having 10,000 to 30,000 kv-a. rating are shown in Fig. 6. The full line curve placed symmetrically with respect to the zero line is the voltage wave of the machine undergoing short-circuit. The dotted symmetrical curve is the short-circuit current, provided the instant of short-circuit occurs at a time when the voltage wave is a maximum or $t = 0.02$ seconds in Fig. 6. (This assumes only reactance in the short-circuit path).

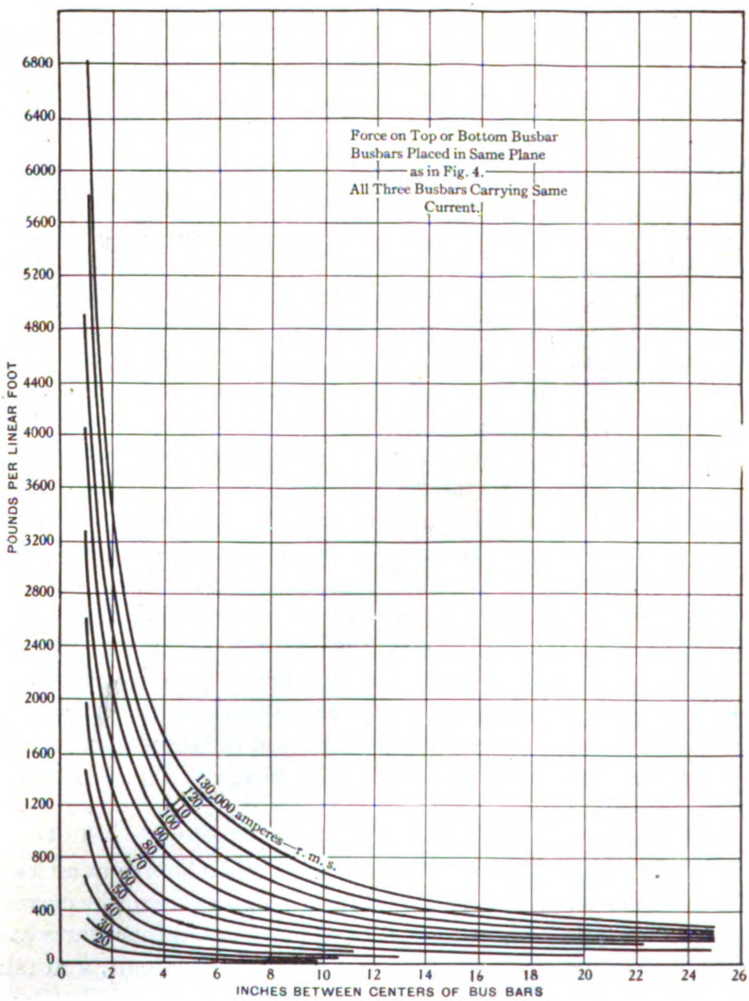


FIG. 5

The assymmetrical current wave in Fig. 6 represents the variation of current if the short circuit takes place at a time t = 0.01 second; that is, at a time when the normal voltage is zero. The first peak value of this assymmetrical current wave is nearly twice the first peak value of the symmetrical current wave. But theoretically it can never be exactly twice the symmetrical value; being slightly decreased on account of the falling off of the exponential current and further by the gradually decreasing voltage wave. The curves of Fig. 6 are plotted with arbitrary scales for a 25-cycle circuit, but from the limiting peak values there shown similar curves can readily be drawn for circuits of any frequency, voltage, and current.

The large current rush at the instant of short circuit, taking place at normal generator induced voltage, represents an enormous amount of power, and lasting for several cycles delivers a considerable amount of energy to the electric conductors undergoing short-circuit and there will inevitably result a rise in temperature in the conductors. Since this energy is stored in the conductor in a comparatively short time, one second as an outside limit, it is clear that very little radiation can occur in this brief interval, and consequently the conductor may have its temperature raised to such a point as to injure the cable insulation, or, if the current is great enough, even melt the conductor itself.

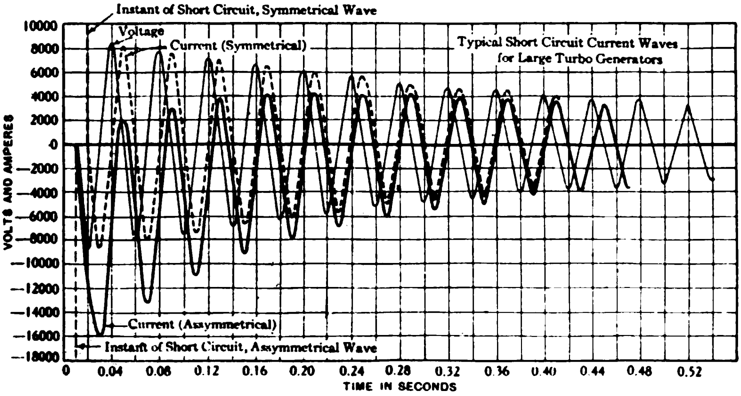


FIG. 6

To determine the heating effect in conductors carrying short-circuit currents of the transient character shown in Fig. 6, the following analysis is given:

First take the symmetrical current wave; that is, the one with its positive and negative waves approximately equal.

Let i = current at any time t.
E_m = peak value of voltage wave at any time.
E_0 = “ “ “ “ “ under sustained short circuit.
Z = ohms impedance in short circuit path.
ϵ = base of hyperbolic logarithms = 2.718.
β = A constant depending on rate of decrease of generated voltage.
R = ohmic resistance in short circuit path considered
ω = $2 \pi n$
n = frequency in cycles per second.
K = a numerical constant.
H = energy
E_1 = peak value of normal voltage wave.

Theory.

$$i = \frac{E_m}{Z} \sin \omega t.$$

$$E_m = (E_1 - E_0)\, \epsilon^{-\beta t} + E_0$$

Hence $i = \frac{1}{Z} [\,(E_1 - E_0)\, \epsilon^{-\beta t} + E_0] \sin \omega t.$

$$\int_0^H d H = \frac{K R}{\omega Z^2} \int_0^t [(E_1 - E_0)^2\, \epsilon^{-2 \beta t} + 2 E_0 (E_1 - E_0)\, \epsilon^{-\beta t} + E_0^2] \sin \omega t\, d\, (\omega t).$$

Integrating

$$H = \frac{K R}{\omega Z^2} \left[\frac{(E_1 - E_0)^2}{4 + \frac{4 \beta^2}{\omega^2}} \times \frac{\omega}{\beta} + \frac{4 E_0 (E_1 - E_0)}{4 + \frac{\beta^2}{\omega^2}} \frac{\omega}{\beta} \right.$$

$$+ \frac{(E_1 - E_0)^2}{4 + \frac{4 B^2}{\omega^2}}\, \epsilon^{-2 \beta t} \left(\sin \omega t \left\{ - \frac{2 B}{\omega} \sin \omega t - 2 \cos \omega t \right\} - \frac{\omega}{\beta} \right)$$

$$+ \frac{2 E_0 (E_1 - E_0)}{4 + \frac{\beta_2}{\omega_2}}\, \epsilon^{-\beta t} \left(\sin \omega t \left\{ - \frac{\beta}{\omega} \sin \omega t - 2 \cos \omega t \right\} - \frac{2\omega}{\beta} \right)$$

$$\left. + E_0^2 \left(\frac{\omega t}{2} - \frac{1}{4} \sin 2\, \omega t \right) \right]$$

or $H = \frac{C\,K\,R}{\omega\,Z^2}$ where C equals the above expression in brackets.

$= \frac{C\,R}{\omega\,Z^2}$ watt seconds. (t in seconds, E in volts, R in ohms, and Z in ohms)

Taking the specific heat of copper as 0.095.

Resistance of copper 11.75 ohms per cir. mil ft.
1 B. t. u. = 1055 joules.
Weight of copper 3.03×10^{-6} lb. per cir. mil ft.

Hence deg. fahr. temperature rise

$$= \frac{C}{\omega\,Z^2}\,\frac{3.86 \times 10^4}{(C.\,M.)^2}$$

$$\text{Temp. rise deg. cent.} = \frac{2.143\,C \times 10^4}{\omega\,Z^2\,(C.M.)^2} \tag{7}$$

From equation (7) the curves of Fig. 7 have been computed. An 11,000-volt system was chosen, three-phase 3/0 B. & S. cable being assumed. The numerical constants taken are as follows:

$$E_1 = \frac{11{,}000}{\sqrt{3}}\sqrt{2} = 8970 \text{ volts.}$$

$$E_0 = \frac{11{,}000 \times 0.07 \times 1.75 \times \sqrt{2}}{\sqrt{3}} = 1100 \text{ volts.}$$

In determining E_0 the generators short-circuited are assumed to have 7 per cent inherent reactance and a sustained short circuit of $1\frac{3}{4}$ times mormal full load current.

cir. mils = 167,800 for 3/0 B. & S. cable.

n = 25 cycles.
β = 2.51 from Fig. 6.

To determine Z, first assume the current for any temperature curve desired, 50,000 amperes, for example. Then the r.m.s. phase voltage $\frac{11{,}000}{\sqrt{3}}$ above, or 6350 volts divided by Z gives the r. m. s. amperes as indicated in Fig. 7.

Thus $\frac{6350}{Z} = 50{,}000$ or $Z = 0.127$ ohms.

This value of Z is then used in equation (**7**). The curves of Fig. 7 have been computed on the assumption that no radiation of heat has taken place between the instant of short-circuit and 0.8 seconds later, all the energy going into the conductor being transformed into heat and stored in the cable as such.

Assuming that the modern oil switch will clear trouble within 0.18 seconds ($4\frac{1}{2}$ cycles on a 25-cycle circuit) after short circuit, it will be noted that should the short-circuit current reach 40,000 amperes (r.m.s. symmetrical) on the initial rush the temperature in any 3/0 conductors carrying such current would be increased approximately 155 deg. cent. At 45,000 amperes the temperature rise is 195 deg. cent., and at 50,000 amperes 235 deg. cent. The melting point of copper is 1085 deg. cent., so the copper is in no danger of melting if the oil switch operates normally. On the other hand, temperatures as high as 200 deg. cent. may injure the cable insulation and later cause trouble from short circuits and will surely result in decreased life.

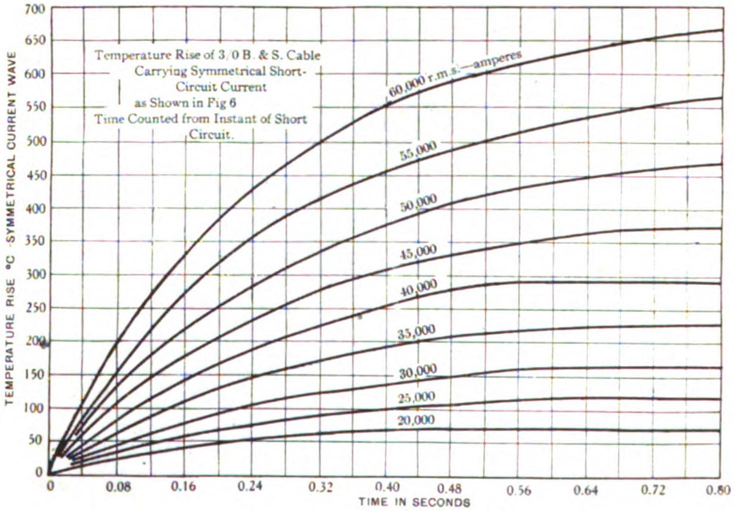


FIG. 7

HEATING OF CABLES CARRYING ASYMMETRICAL CURRENT WAVE

To determine the heating effect of the asymmetrical current wave, it is merely necessary to follow the same general procedure as described above for the symmetrical wave.

First, obtain the expression for the instantaneous current, then square and integrate and convert to heat units, and then into temperature rise for any given size cable.

The notation is the same as that given under the analysis for heating with a symmetrical current wave, with the following additions. All voltages, currents, and impedances are *per phase* values.

α = a constant depending on the rate of falling off of the asymmetrical current over and above the rate of falling off of the symmetrical wave.

A = a constant depending on the instant of short circuit.

$= \mp \frac{E_1}{Z}$ for maximum displacement of asymmetrical wave, $-$ when the asymmetrical wave is on the negative side of the zero line and $+$ when on the positive side of the zero line.

Theory.

$$E_m = (E_1 - E_0)\,\epsilon^{-\beta\left(t-\frac{\pi}{2\omega}\right)} + E_0.$$

$$i = \frac{E_m}{Z}\sin(\omega t) + A\,\epsilon^{-\alpha\left(t-\frac{\pi}{2\omega}\right)}$$

$$\int_0^H dH = \frac{KR}{\omega}\int_{\pi/2\omega}^{t}\left[\frac{E_m}{Z}\sin wt + A\epsilon^{-\alpha\left(t-\frac{\pi}{2\omega}\right)}\right]^2 d\,\omega t \qquad (8)$$

Hence t_1 the time after the short circuit takes place $= t - \pi/2\omega$. In the above equation t cannot be less than $\pi/2\omega$. Substituting E_m in equation (8), integrating, and substituting limits,

$$\frac{H}{KR} = \frac{1}{\omega}\left(\frac{E_1 - E_0}{Z}\right)^2 \epsilon^{\frac{\beta\pi}{\omega}}\left[\frac{\epsilon^{-2\beta t}}{4+\frac{4\beta^2}{\omega^2}}\left(\sin\omega t\left\{-\frac{2\beta}{\omega}\sin\omega t\right.\right.\right.$$

$$\left.\left.\left.-2\cos\omega t\right\} - \frac{\omega}{\beta}\right) + \frac{\epsilon^{-\frac{\beta\pi}{\omega}}}{4+\frac{4\beta^2}{\omega^2}}\left(\frac{\omega}{\beta} + \frac{2\beta}{\omega}\right)\right]$$

$$+\frac{1}{\omega}\left(\frac{E_0}{Z}\right)^2\left[-\frac{1}{2}\cos\omega t\sin\omega t + \frac{\omega t}{2} - \frac{\pi}{4}\right]$$

$$+\frac{2}{\omega}\left(\frac{E_1-E_0}{Z}\right)\frac{E_0}{Z}\epsilon^{+\frac{\beta\pi}{2\omega}}\left[\frac{\epsilon^{-\beta t}}{4+\left(\frac{\beta}{\omega}\right)^2}\left(\sin\omega t\ \left\{-\frac{\beta}{\omega}\sin\omega t\right.\right.\right.$$

$$\left.\left.\left.-\ 2\cos\omega t\right\}\ -\frac{2\,\omega}{\beta}\right)+\frac{\epsilon^{-\frac{\beta\,\pi}{2\,\omega}}}{A+\left(\frac{\beta}{\omega}\right)^2}\left(\frac{\beta}{\omega}+\frac{2\,\omega}{\beta}\right)\right]$$

$$-\frac{A^2\,\epsilon^{\frac{\alpha\pi}{\omega}}}{2\,\alpha}\left[\epsilon^{-2\,\alpha\,t}-\epsilon^{-\frac{\alpha\,\pi}{\omega}}\right]$$

$$+\frac{2\,A}{\omega}\left(\frac{E_1-E_0}{Z}\right)\epsilon^{(\alpha+\beta)\frac{\pi}{2\,\omega}}\left[\frac{\epsilon^{-(\alpha+\beta)\,t}\left(-\frac{\alpha+\beta}{\omega}\sin\omega t-\cos\omega t\right)}{1+\left(\frac{\alpha+\beta}{\omega}\right)^2}\right.$$

$$\left.+\frac{\epsilon^{-(\alpha+\beta)\frac{\pi}{2\,\omega}}\left(\frac{\alpha+\beta}{\omega}\right)}{1+\left(\frac{\alpha+\beta}{\omega}\right)^2}\right]$$

$$+\frac{2\,A}{\omega}\,\frac{E_0}{Z}\,\epsilon^{\frac{\alpha\,\pi}{2\,\omega}}\left[\frac{\epsilon^{-\alpha\,t}\left(-\frac{\alpha}{\omega}\sin\omega t-\cos\omega t\right)}{1+\left(\frac{\alpha}{\omega}\right)^2}\right.$$

$$\left.+\,\epsilon^{-\frac{\alpha\,\pi}{2\,\omega}}\left(\frac{\alpha}{\omega}\right)\frac{1}{1+\left(\frac{\alpha}{\omega}\right)^2}\right] \qquad (9)$$

Denoting the right-hand side of the equation by $D/Z^2\omega$,

$$H = \frac{K\,R\,D}{\omega\,Z^2}$$

$$= \frac{D\,R}{\omega\,Z^2}$$ watt-seconds. (t in secs., E in volts, R in ohms and Z in ohms.)

As in the symmetrical current wave, temperature rise deg. cent.

$$= \frac{2.143\, D \times 10^4}{\omega Z^2 \ (\text{C. } M.)^2} \qquad \textbf{(10)}$$

This equation is similar to equation (**7**) and, in solving, the same circuit constants are used, with the addition of α, which has been determined as 8.65 from the curves of Fig. **6**.

From the above equation (**10**) the temperature rise curves of Fig. 8 have been computed, and marked "r.m.s. amperes." To avoid any ambiguity as to the meaning of the term r.m.s. amperes as applied to the asymmetrical wave of Fig. 6, take the following example. Let a three-phase, 11,000-volt generator be short-circuited across its own terminals. The phase voltage will be $11{,}000/\sqrt{3} = 6350$ volts. Let the impedance of the machine be 0.127 ohms per phase. Then the r.m.s. short-circuit current is 6350/0.127, or 50,000 r.m.s. amperes. Any 3/0 conductor carrying this current will have its temperature in-

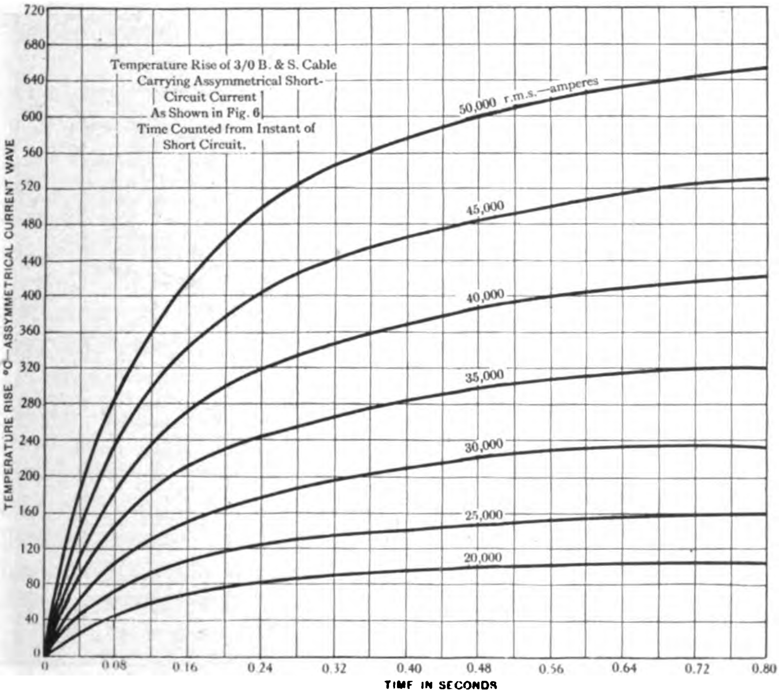


FIG. 8

creased according to the temperature rise curve marked " 50,000 r. m. s. amperes " in Fig. 7, if the wave is symmetrically placed about the zero axis as the dotted curve in Fig. 6.

If the short circuit takes place at such a point of the voltage wave that the current is almost totally displaced one side of the zero line as the full line current curve of Fig. 6, then the heating of 3/0 conductor carrying the 50,000 r.m.s. amperes asymmetrical as above indicated, will follow the temperature rise curve marked " 50,000 r. m. s. amperes " in Fig. 8.

Thus, by a simple application of Ohm's law to determine the r.m.s. current, the heating of a 3/0 conductor with either the symmetrical or asymmetrical current wave, can be determined from Figs. 7 and 8 respectively. The curves in these last two figures apply only to 3/0 B. & S. cable and currents which decrease in accordance with the current waves of Fig. 6. However, by the use of equations (7) and (10) the heating produced by any symmetrical or asymmetrical current waves and for any size cable may be determined.

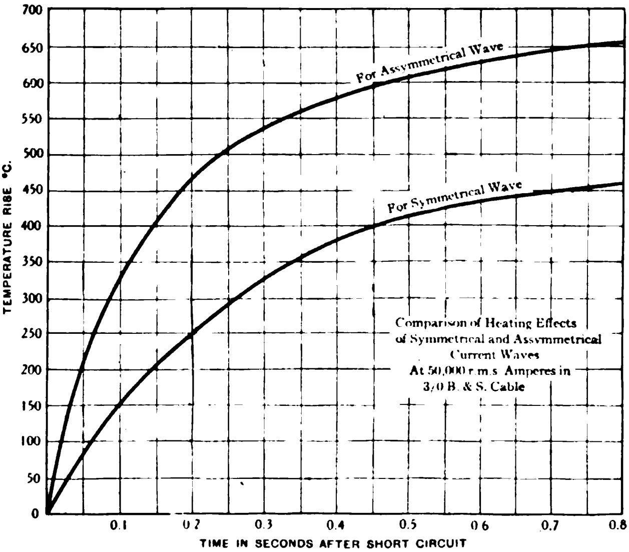


FIG. 9

To compare the heating effect of the symmetrical and asymmetrical current waves for the same r.m.s. current, the two curves of Fig. 9 have been plotted. These curves represent the temperature rise for 50,000 amperes r.m.s. in 3/0 B. & S. cable. It will be observed that the heating due to the asymmetrical current is very much in excess of that due to the symmetrical wave. For example, in this case the relative heating with the same r.m.s. current is as follows:

Secs. after short-circuit	$\frac{\text{Asymmetrical Current Temp. Rise}}{\text{Symmetrical Current Temp. Rise.}}$
0.05	2.47
0.10	2.20
0.20	1.825
0.40	1.52
0.60	1.46
0.80	1.425

This relation between relative heating with the two types of current waves holds for all values of current, since at any particular point of time the temperature rise is proportional to the square of the current, and this relation holds for each set of temperature rise curves.

It will be seen from the above table that the ratio of temperature rise for the two types of current curves is approaching a constant value of approximately 1.4. It is clear that the ratio cannot fall much below this value at any time greater than 0.8 seconds, since the amount of energy stored in the cable as heat after this interval is comparatively small, due to the rapid falling off of the current. Further, it is probable that after one second radiation would materially affect the temperature of the copper, and analysis beyond this point must necessarily be incomplete.

While the temperature rise of the 3/0 copper cable carrying short-circuit current is relatively high at reasonable values of current (465 deg. cent. at 50,000 amperes asymmetrical, and 250 deg. cent. for the same symmetrical current at the end of 0.18 sec.) there is still a means of materially and effectively reducing these temperatures in any new system, if possible temperature rise is the limiting feature of the high-tension power circuit. This is by increasing the normal kilovolt-ampere rating of the underground cables.

Referring to equations (7) and (10) it will be observed that the temperature rise is inversely proportional to the square of the circular mils of copper, that is, to the square of the cross-section of the conductor in which the short-circuit current flows. Thus, if the cross-section of the conductor is doubled, the temperature rise is only one-quarter as great. From the relation between temperature rise and conductor cross-section given in equations (7) and (10), and the temperature rise curves of Figs. 7 and 8, the curves of Figs. 10, 11, 12 and 13 have been computed. These

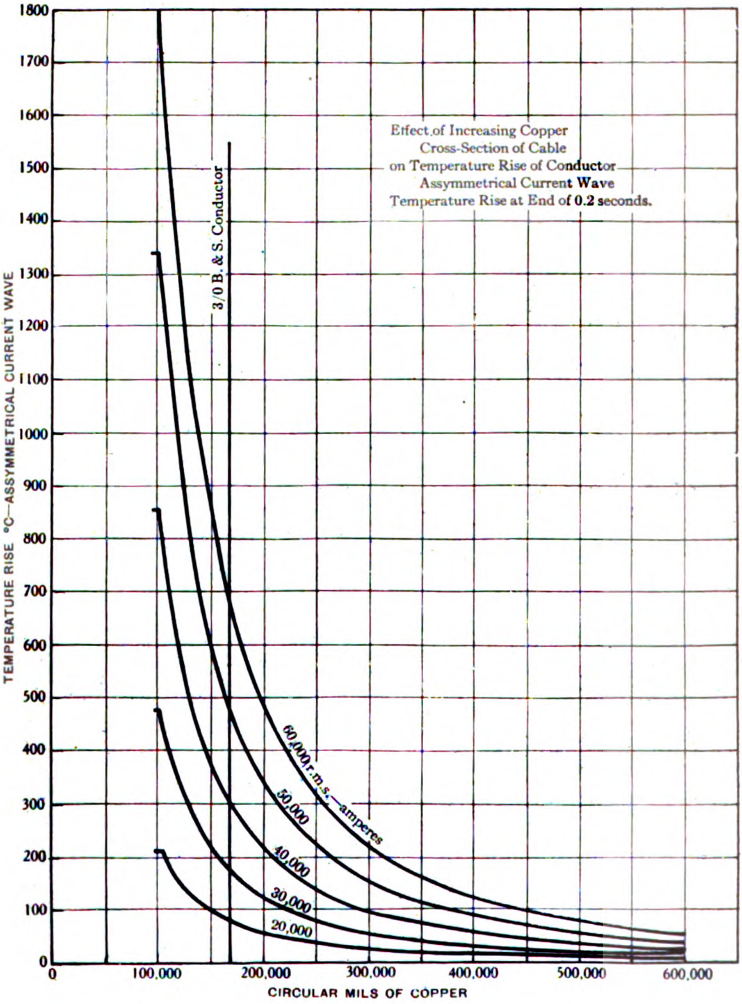


FIG. 10

show graphically the rapid decrease of temperature rise of the copper carrying short-circuit current as the circular mils of the conductor is increased. Figs. 10 and 11 represent temperature rise for various size conductors at the end of 0.2 and 0.5 seconds respectively, when carrying an asymmetrical current wave as shown in Fig. 6. In Figs. 12 and 13 are shown similar curves for the symmetrical current wave of Fig. 6.

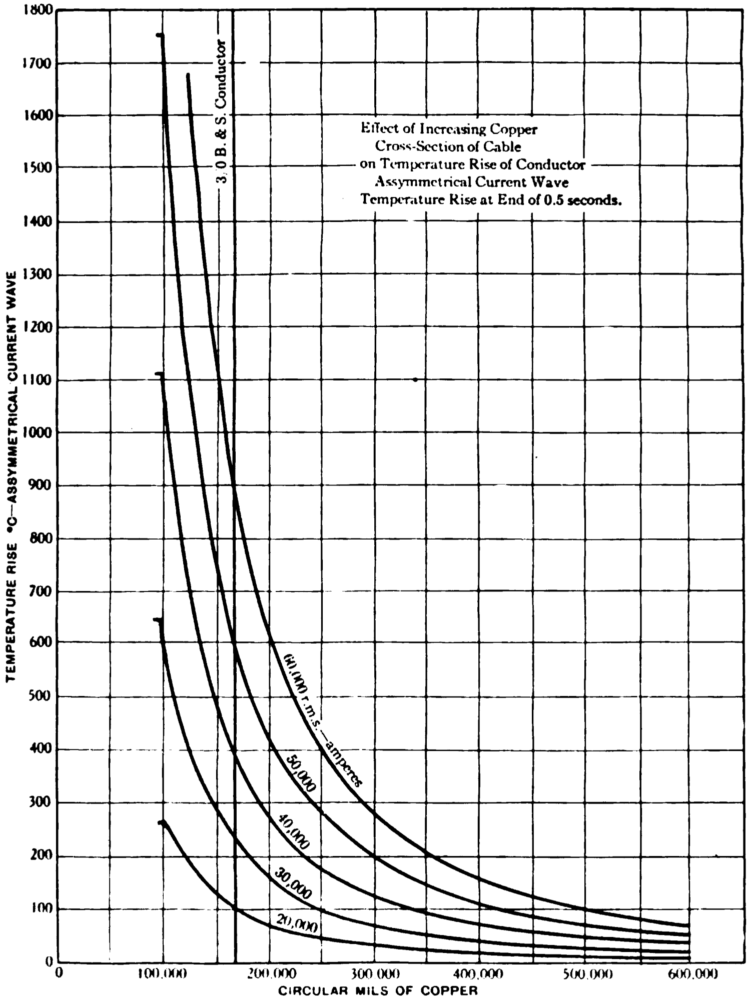


FIG. 11

For illustration, take the temperature rise curves of Fig. 10, computed for an asymmetrical current of 50,000 amperes. If 3/0 B. & S. conductor carries the short-circuit current, its temperature will be raised 480 deg. cent. in 0.2 seconds. If the conductor has a cross-section of 250,000 cir. mils the temperature rise will be only 217 deg. cent., and if it has 300,000 cir. mils cross-section, the rise will be still further reduced to 150 deg. cent. in the same time.

It has therefore been possible, as above shown, to reduce the maximum temperature rise in a conductor carrying short-circuit current to within reasonable limits, by increasing the cross-section of the cable. It may be maintained that the increased size of cable will reduce the total impedance in the short-circuit path and a larger current will flow than when using a smaller size cable. It should be borne in mind, however, that the maximum short-circuit current will obviously exist in a power system when the short circuit is nearest the power house, and the additional cable length in the short-circuit path, assuming the trouble to

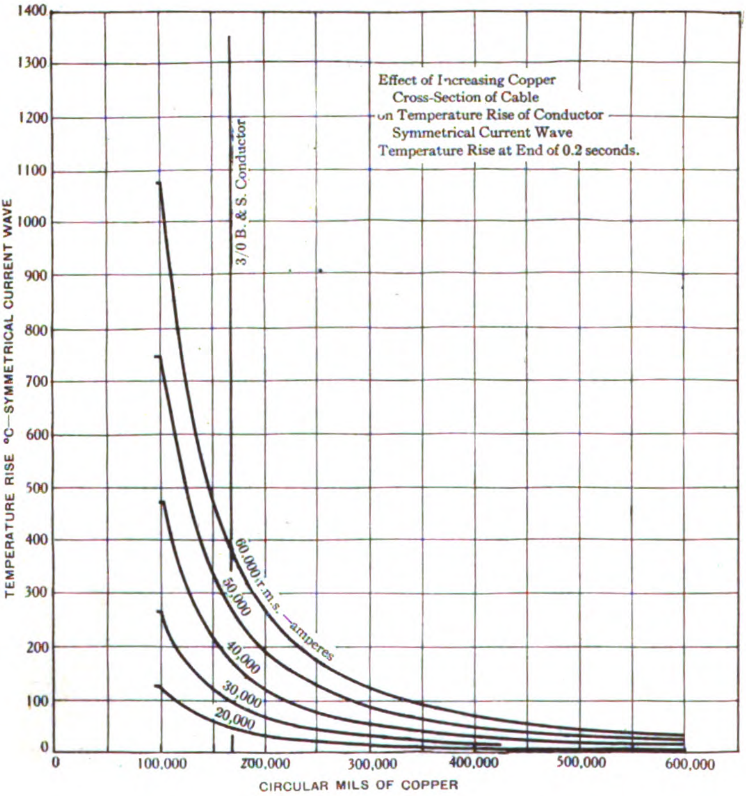


FIG. 12

occur at a short distance from the power house, will merely reduce the current below the maximum value which could exist if the short circuit took place at the power house.

For example, if a given power system has a maximum short-circuit current output of 50,000 amperes, with the short-circuit occurring just outside the feeder oil switch at the power house, any other location of trouble on that feeder will necessarily give a current smaller than 50,000 amperes; and this is true independent of the size of the feeders. If the short circuit should occur

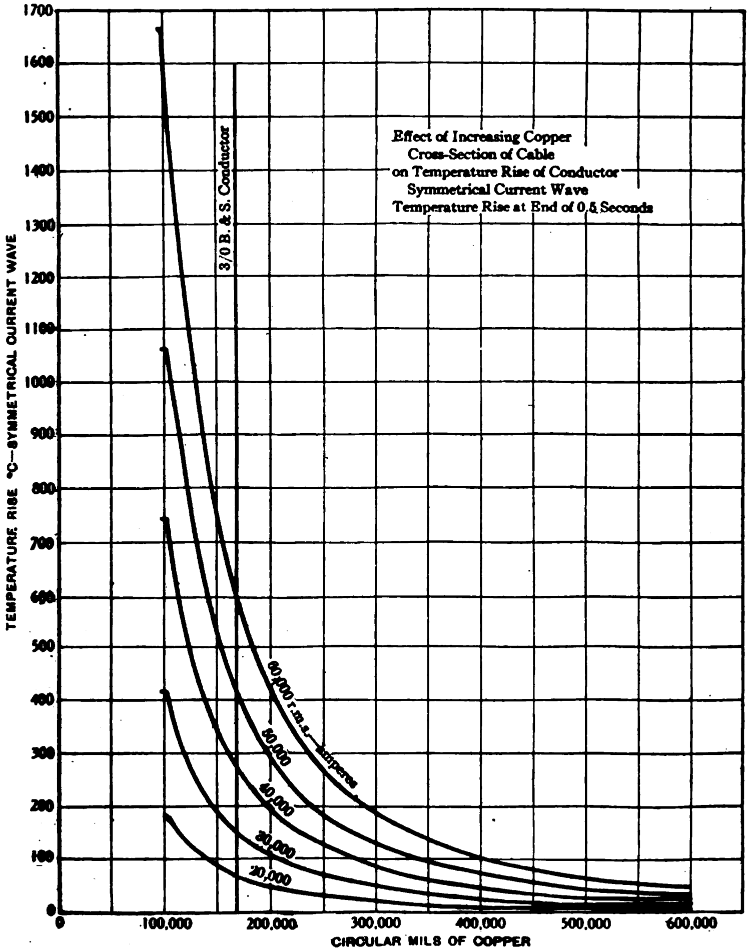


Fig. 13

several miles from the power house the impedance of the cable would materially reduce the current below 50,000 amperes, and the smaller the cable the greater would be this reduction.

For cases of short circuit close to a power house using reactors to limit its abnormal current flow, the impedance of that part of the cable in the short circuit path is such a small percentage of the total impedance opposing the current flow that its value for any reasonable size cable is absolutely negligible.

With the possibility of the destructive forces and temperatures in cables and busbars as computed above well in mind, it is now intended to show how these short-circuit currents may be effectively controlled.

USE OF REACTORS IN LIMITING CURRENT FLOW UNDER SHORT CIRCUIT CONDITIONS

Reactors, as mentioned in the earlier part of this paper, have recently been extensively used in reducing possible current flow into a fault, and several different schemes of arrangement in a power system have been devised and are now in use.

The schemes of introducing reactance in the power circuits which are at present well recognized, are as follows:

1. Reactance in generators and generator leads.
2. Artificial reactance in the separate feeders.
3. Reactance in the main power house bus between generators.

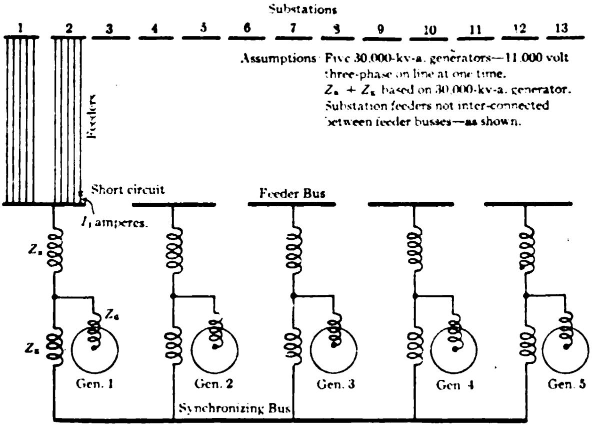
Then, to be sure, there are various combinations of the three above schemes which can be used.

There is, moreover, another system of arranging reactors in a power system recently brought to light by Mr. Stott and briefly described by him in discussing the paper of Messrs. Lyman, Perry and Rossman at the mid-winter convention, February, 1914. This scheme, upon analysis, has proved of such merit that it is here analyzed and discussed at some length.

In general, the scheme consists of paralleling all generators through reactors on a synchronizing or transfer bus, and taking power through a separate set of reactors direct from each generator, rather than from the synchronizing bus (what would ordinarily be the main station bus). The scheme is shown diagrammatically in Fig. 14. For convenience of reference, Z_G is called the generator reactance, either inherent, or inherent plus external. Z_K is called the synchronizing reactance, being placed partly for synchronizing purposes but more especially to limit abnormal current flow, and Z_B is called the feeder bus reactance, being in the path of direct feed from the generator to the feeder bus.

For purposes of analysis, a power house with an installed capacity of 180,000 kv-a. in 30,000-kv-a. generators, that is, six machines, only five being used at any one time, is taken. Also a system with a nominal voltage of 11,000 volts is used in determining current flow, and 3/0 three-conductor 3217-kv-a. cables are assumed where considered in computations. All per cent reactance where used, except feeder reactance, is based on the maximum 30,000 kv-a. rating of one machine. For example, if Z_B, Z_C, or Z_K is spoken of as say 3 per cent, it is understood that when any one of these reactors is carrying rated current of one machine the voltage drop across that reactor is 3 per cent of rated phase voltage, or $\frac{11{,}000}{\sqrt{3}} \times 0.03 = 190.5$ volts, and has a reactance of

$$\frac{190.5 \times 11{,}000 \times \sqrt{3}}{30{,}000{,}000} = 0.121 \text{ ohms.}$$



Assumptions: Five 30,000-kv-a. generators—11,000 volt three-phase on line at one time.
$Z_G + Z_K$ based on 30,000-kv-a. generator.
Substation feeders not inter-connected between feeder busses—as shown.

Scheme S-1

FIG. 14

In speaking of feeder reactance, its value is based on the kv-a. rating of the cable. For example, a 5 per cent feeder reactance the feeder being rated at 3217 kv-a. has a voltage drop of $(11{,}000/\sqrt{3}) \times 0.05 = 317.5$ volts and a reactance of

$$\frac{317.5 \times 11{,}000 \times \sqrt{3}}{3{,}217{,}000} = 1.878 \text{ ohms.}$$

DETERMINATION OF SHORT-CIRCUIT CURRENT

In determining the short circuit currents in the various networks presented, the following equations were used. All equations are vector equations, but where the resistance involved is negligibly small in comparison to the reactance, the equation may be solved algebraically and the resistance values ignored. This cannot be done in scheme *S*-2, and here the equation for the short circuit current must be solved vectorially.

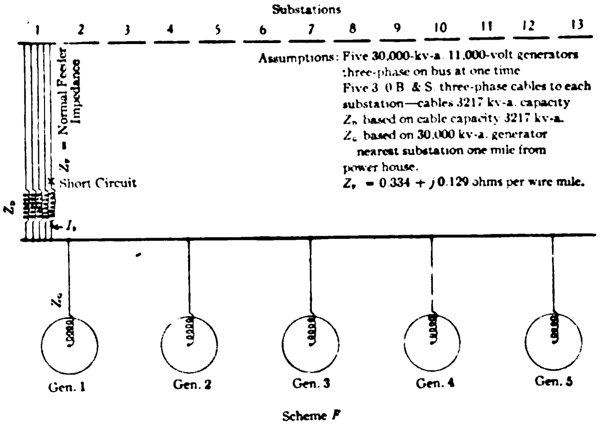

Substations
1
2
3
4
5
6
7
8
9
10
11
12
13
Assumptions: Five 30,000-kv-a. 11,000-volt generators three-phase on bus at one time
Five 3 0 B. & S. three-phase cables to each substation—cables 3217 kv-a. capacity
Z_n based on cable capacity 3217 kv-a.
Z_G based on 30,000 kv-a. generator nearest substation one mile from power house.
Z_f = 0.334 + j 0.129 ohms per wire mile.
Z_f = Normal Feeder Impedance
Short Circuit
Z_n
I_1
Z_G
Gen. 1
Gen. 2
Gen. 3
Gen. 4
Gen. 5
Scheme F

FIG. 14b.

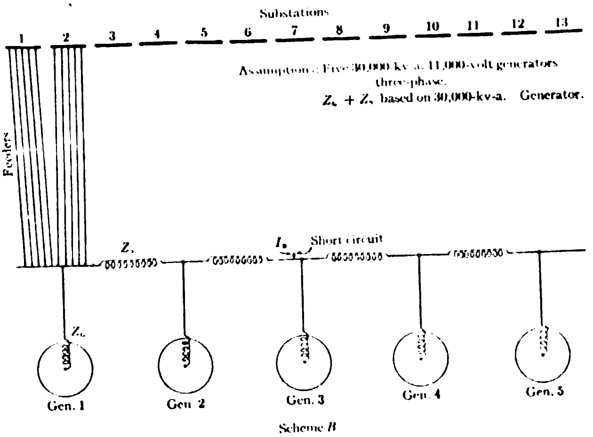

Substations
1
2
3
4
5
6
7
8
9
10
11
12
13
Assumptions: Five 30,000-kv-a. 11,000-volt generators three-phase.
Z_G + Z_s based on 30,000-kv-a. Generator.
Feeders
Z_s
I_s
Short circuit
Z_G
Gen. 1
Gen. 2
Gen. 3
Gen. 4
Gen. 5
Scheme H

FIG. 14c.

The ratio of reactance to resistance in all reactance coils and in the generator itself has been taken as 21.5 where it was necessary to use the resistance values.

Scheme S-1. *Fig.* 14.

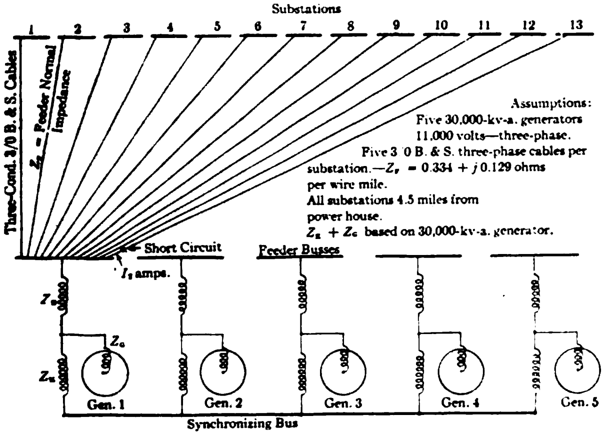
$$I_1 = \frac{E}{Z_G + Z_B - \frac{4\,Z_G^{\,2}}{5\,(Z_K + Z_G)}} \qquad \textbf{(15)}$$

Scheme F. Fig. 14*b*. Feeders open at substation end

$$I_F = \frac{E_G}{Z_D + \frac{Z_G}{5}} \tag{16}$$

Scheme F. Fig. 14 *b*. Feeders paralleled at substation end

$$I_F = \frac{E}{Z_G\left(\frac{Z_D + Z_F}{5\,Z_F}\right) + Z_D} \tag{17}$$


Substations
1
2
3
4
5
6
7
8
9
10
11
12
13
Three-Cond. 3/0 B. & S. Cables
Z_F = Feeder Normal Impedance
Assumptions:
Five 30,000-kv-a. generators
11,000 volts—three-phase.
Five 3/0 B. & S. three-phase cables per substation.—Z_F = 0.334 + j 0.129 ohms per wire mile.
All substations 4.5 miles from power house.
Z_K + Z_G based on 30,000-kv-a. generator.
Short Circuit
I_2 amps.
Feeder Busses
Z_B
Z_G
Z_K
Gen. 1
Gen. 2
Gen. 3
Gen. 4
Gen. 5
Synchronizing Bus

Scheme *S*-2

FIG. 14a.

Scheme B. Fig. 14*c*.

$$I_B = \frac{E\,(5\,Z_G + 4Z_G\,Z_S + Z_S{}^2)}{Z_G{}^3 + 2Z_S\;Z_G^2 + Z_S{}^2\,Z_G} \tag{18}$$

Scheme S-2. *Fig.* 14*a* Thirteen substations—5 feeders per substation

$$\begin{aligned} I_2 = E\left(5 + \frac{5\,Z_K}{Z_G}\right)&\left[\frac{305}{48}Z_B + Z_K\left(\frac{305}{48} + \frac{305}{48}\frac{Z_B}{Z_G}\right)\right. \\ &\left. + \frac{25}{48}Z_F\left(1 + \frac{Z_K}{Z_G}\right)\right] - \frac{13}{12}Z_G{}^2 + \left[Z_G + Z_K\left(5 + 5\frac{Z_B}{Z_G}\right)\right. \\ &\left. + 5Z_B\right]\;\left[\frac{13}{12}Z_G + \frac{65}{48}Z_K\left(1 + \frac{Z_B}{Z_G}\right)\right. \\ &\left. + \frac{65}{48}Z_B + \frac{25}{48}Z_F\;\left(1 + \frac{Z_K}{Z_G}\right)\right] \end{aligned} \tag{19}$$

E = generator phase voltage (line to neutral.)
Z = impedance

Equations (**17**) and (**19**) must be solved vectorially; as above noted, the others may be solved, without loss of accuracy, algebraically, if the resistance r of any reactor having an impedance $r + j\,x = Z$, is small in comparison to the reactance x. This is true, in general, for reactors, namely r/x is negligibly small.

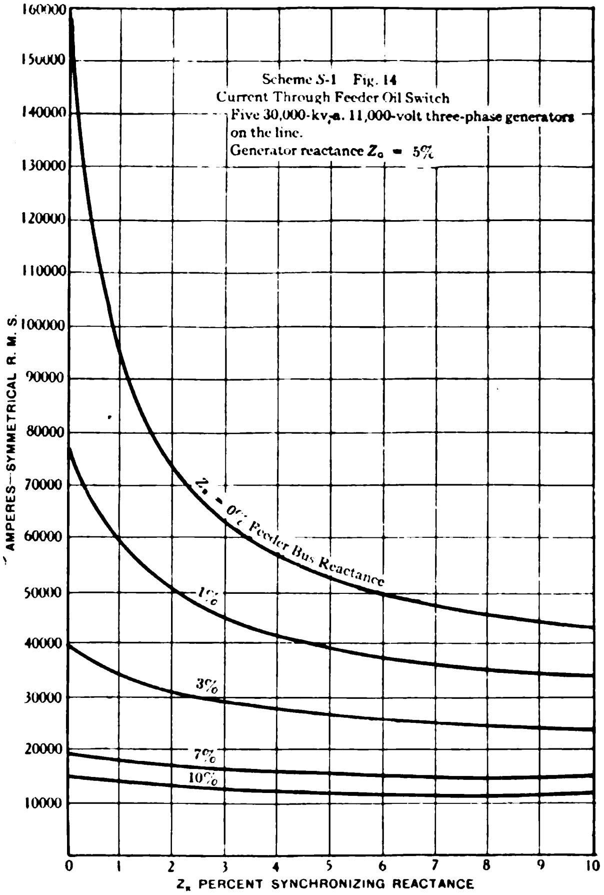


FIG. 15

The above equations were determined for the several cases by the simple application of Ohm's law applied to alternating-current circuits.

From equation (**15**) the short-circuit current curves of Figs. 15 to 21 inclusive have been calculated. Figs. 15 to 19 inclusive show the effect of varying the feeder bus and synchronizing reactance Z_B and Z_K respectively, as the reactance of the machine varies from 5 to 25 per cent, inclusive.

For example, with the 150,000-kv-a. running capacity assumed, suppose it is desired to limit the short-circuit current to 30,000 amperes, the generators having an inherent reactance of 5 per cent. From Fig. 15, it is clear that this may be done by a variety of combinations of feeder bus reactance and synchronizing reactance, approximately as follows:

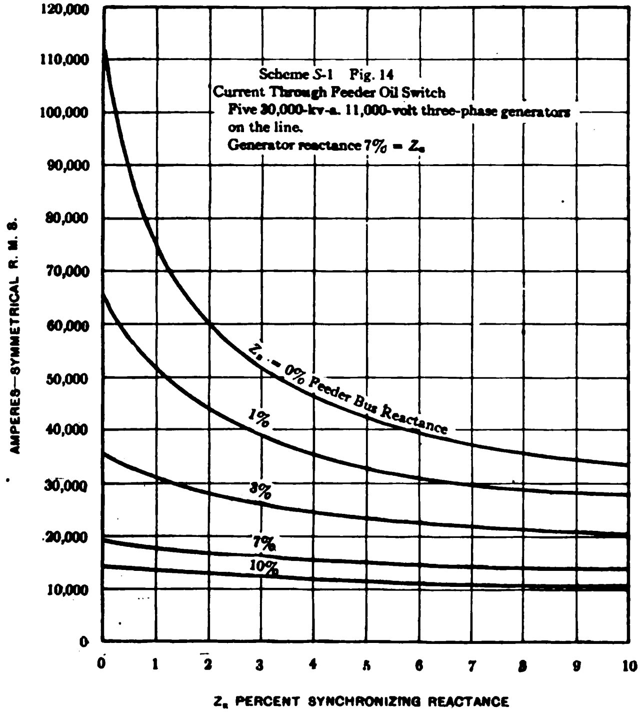


FIG. 16

Short-circuit amperes	% Z_B	% Z_K	Total % Z
30,000	4.3	0	4.3
30,000	3.0	2.5	5.5
30,000	2.5	5.0	7.5
30,000	2.0	8.0	10.0
30,000	1.6	10.0	11.6

The total Z above is exclusive of the generator reactance. Similar examples can be taken for the curves of Figs. 16 to 19 inclusive, if desired. From the above table it is clear that for a given short-circuit current, when the trouble occurs on the feeder bus, the least reactance is required when that reactance is placed between the feeder bus and the generator, that is, in Z_B. This could have been easily foreseen, since it is clear that with a given reactance in use, the larger the amount in the path of the total current, the smaller will be that current.

It is further obvious from the curves of Figs. 15 to 19 inclusive that the larger the feeder bus reactance, Z_B, the smaller the effect of the synchronizing reactance in further reducing the short-circuit current. This is brought out by the curves in Figs. 15 to 19, where Z_B = 10 per cent. For example, in Fig. 15, with generators having 5 per cent reactance and the feeder bus reactance 10 per cent, the short-circuit current only decreases from 14,000 to 11,500 amperes as the synchronizing reactance increases from zero to 10 per cent.

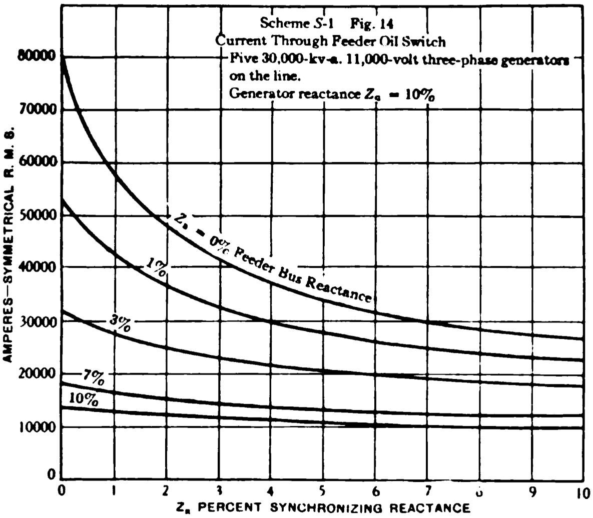


FIG. 17

When the feeder bus reactance is low the synchronizing reactance is useful in reducing the current in short circuits which occur outside the feeder oil switch. But when the feeder bus reactance reaches 5 per cent or greater, the effectiveness of Z_K

in further reducing current flow becomes practically nil. This statement is clearly borne out by a study of curves of Figs. 15 to 19 inclusive and also in Figs. 20 and 21. Still using scheme *S*-1, the curves of Figs. 20 and 21 have been plotted from equation (**15**) (the dotted curves have been plotted from the following

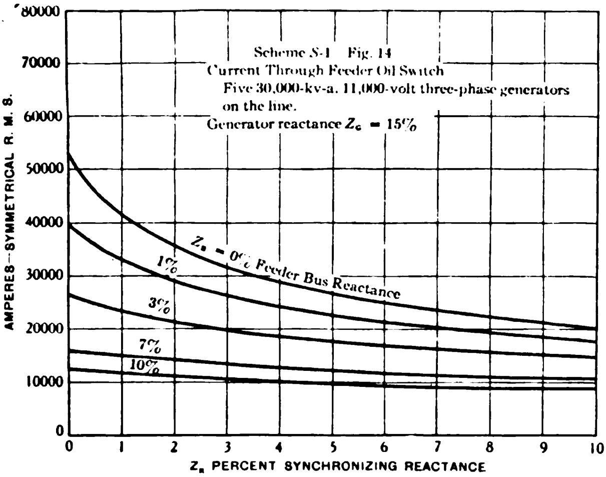


FIG. 18

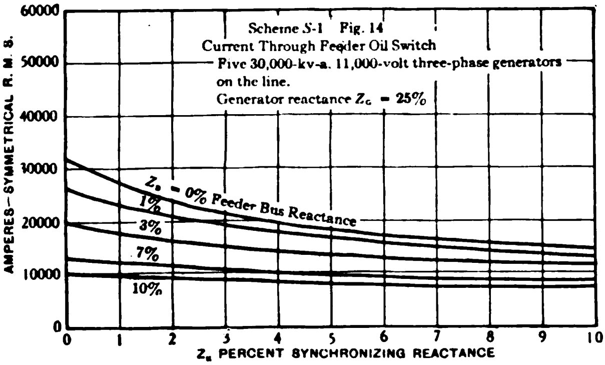


FIG. 19

equations: Fig. 20, amperes = E/Z_B, and Fig. 21, amperes = $E/Z_G + E/Z_K$).

LIMITING EFFECTIVE VALUE OF Z_B

It is here shown in Fig. 20 that if the synchronizing reactance is not used the feeder bus reactance loses rapidly in effectiveness after 5 per cent is reached. The dotted curve represents conditions with an infinite generator capacity on the line and no synchronizing reactance Z_K used. The generators for this curve may have any reactance whatsoever.

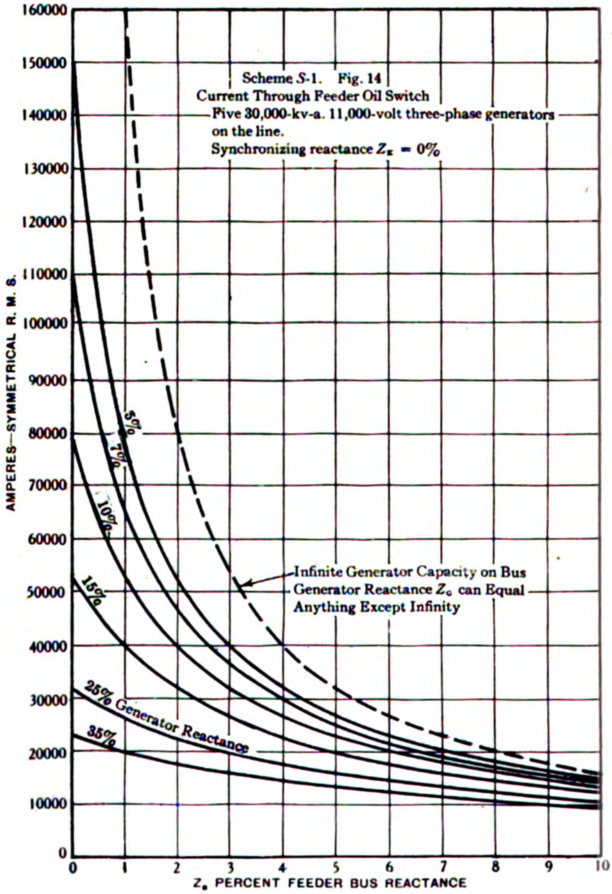


FIG. 20

LIMITING EFFECTIVE VALUE OF Z_K

From Fig. 21, it is clear that the effectiveness of Z_K in reducing currents from short circuit beyond the feeder oil switch falls off rapidly after a value of 3 per cent is reached and for comparatively large reactance in the generator, an increase above 1 per cent in Z_K is practically useless.

The dotted curve of Fig. 21 shows the limiting value of short-circuit current when there is an infinite generator capacity on the bus and all generators have 5 per cent reactance. If the generator reactance were higher the limiting curve would be lower. The curves of Fig. 21 assume Z_B equal to zero.

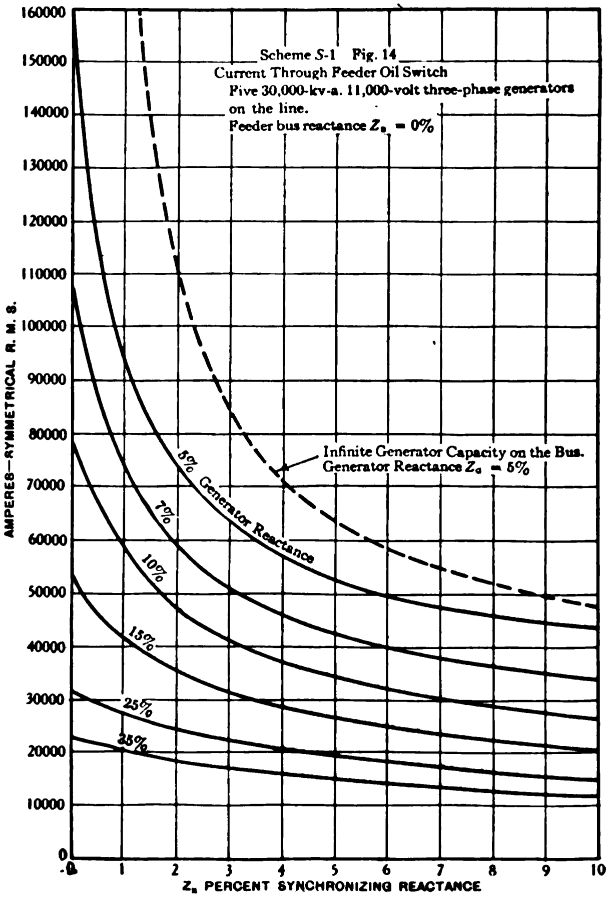


FIG. 21

The use of the synchronizing reactance would at first seem somewhat superfluous when the feeder bus reactance is used, but it is located not only to reduce the current in a short circuit which occurs at the power house beyond the feeder oil switch but also to reduce the current should the short circuit occur on the synchronizing bus, and further to limit the current flow in the event of poor synchronizing.

The effectiveness of Z_K in reducing the maximum current flow when the fault occurs on the synchronizing bus is shown graphically in Fig. 22. With Z_K = 3 per cent and generators having

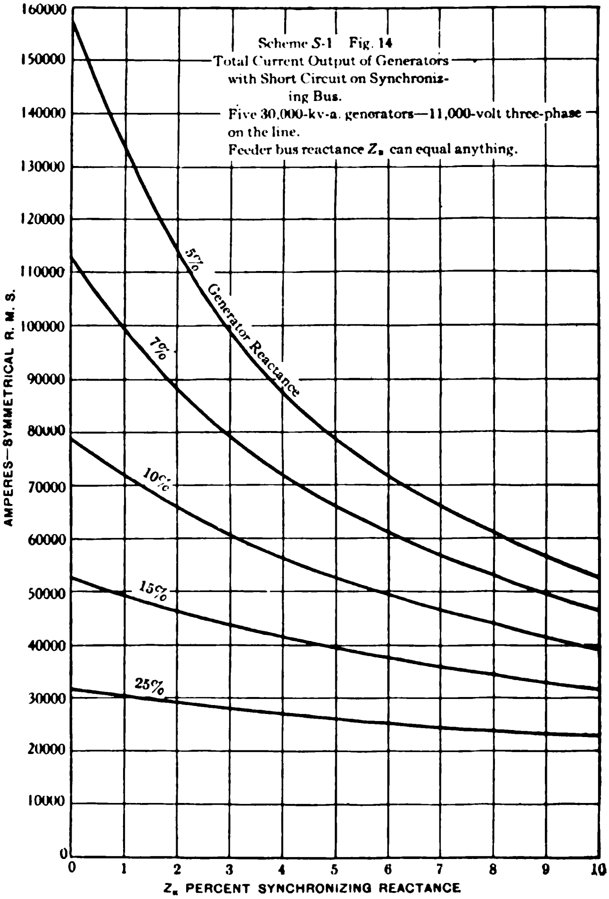


Fig. 22

5 per cent reactance, the current is reduced from 157,500 to 99,000 amperes. Machines having 7 per cent reactance have a current reduction from 112,500 to 79,000 amperes. With the 5 per cent reactance machines there has been a 37 per cent current reduction; with the 7 per cent reactance generators, a 30

per cent reduction by the use of the 3 per cent synchronizing reactance.

While the currents shown in Fig. 22 are comparatively large, it should be observed that these currents cannot exist in any one conductor since they represent the total instantaneous output of the five machines. Thus the largest current which can exist in any one conductor is 4/5 of the values shown in Fig. 22. Further, this current does not exist in the cable line but circulates only in the machine and synchronizing bus circuit.

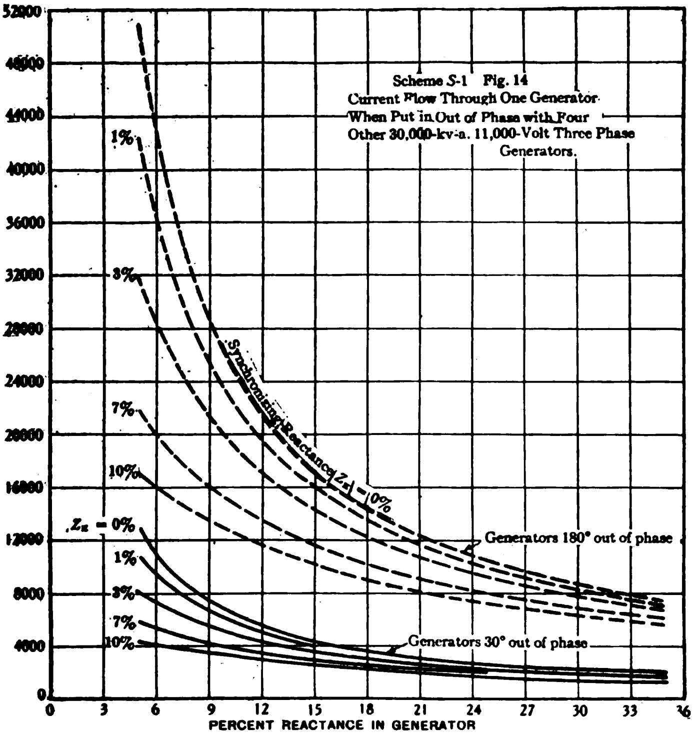


FIG. 23

POOR SYNCHRONIZING

As mentioned earlier in this paper, the purpose of Z_K, the synchronizing reactance, is partly to furnish protection against short circuits on the system and partly to be of aid in limiting current in times of poor synchronizing. If four machines should be running and the fifth then put on the line 180 electrical degrees out of phase, the upcoming machine would have circulating in its windings a current considerably in excess of its maximum short-circuit current, provided no synchronizing reactance Z_K is used. The effectiveness of Z_K in reducing this current is shown graphically in Fig. 23 for various values of generator reactance, when one machine is thrown on the line both 180 electrical degrees out of phase (dotted curves) and also for 30 degrees (full line curves).

Should it be desired to raise the value of Z_K so that the maximum current which can flow in any generator thrown on the line 180 degrees out of phase is equal to the normal short-circuit current of one machine, it can be shown that the value of Z_K bears a fixed relation to the generator reactance depending on the number of generators on the line.

Let E = rated phase voltage $= \frac{11{,}000}{\sqrt{3}}$ for 11,000-volt system.

I_z = circulating armature current in machine thrown on line 180 electrical degrees out of phase.

Z_G = per cent generator impedance.

Z_K = per cent synchronizing impedance.

I_S = normal short circuit current of one machine.

n = number of generators running after "out of step" machine has been put on line.

Then

$$I_z = \frac{2E}{Z_G + Z_K + \dfrac{Z_G + Z_K}{n - 1}}$$

Upcoming generator 180 electrical degrees out of phase.

$$I_S = \frac{E}{Z_G}$$

Or, if I_z is to equal I_S,

$$E/Z_G = 2E/\left(Z_G + Z_K + \frac{Z_G + Z_K}{n - 1}\right)$$

Simplifying

$$Z_K = \frac{n - 2}{n} Z_G \tag{12}$$

In this equation n obviously cannot be less than 2.

For 120 electrical degrees between upcoming machine and line voltages

$$Z_K = \frac{0.732\,n - 1.732}{n} Z_G \tag{13}$$

and for 90 deg. phase displacement

$$Z_K = \left(\frac{0.414\, n - 1.414}{n}\right) Z_G \qquad (14)$$

From equations (**12**), (**13**) and (**14**) the curves of Fig. 24 are drawn. These curves show the relation between the value of Z_K and Z_G for a different number of machines running. Clearly this relation is independent of the kilovolt-ampere rating of the machine or its per cent reactance.

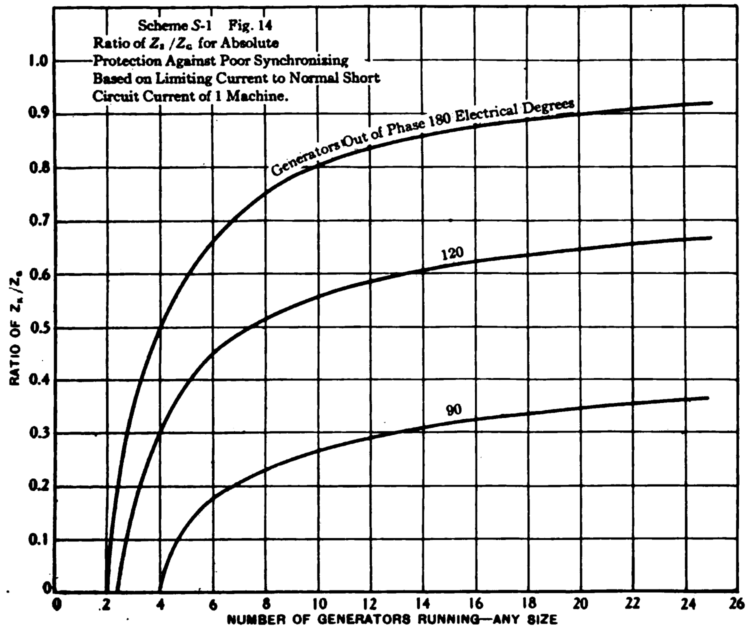


FIG. 24

With a small number of machines running, five for example, Z_K need not exceed 0.6 Z_G for protection of generators against mechanical injury due to the worst possible conditions of poor synchronizing. Thus with generators having 7 per cent inherent reactance the synchronizing reactance need not exceed 4.2 per cent for absolute protection to the generators. This assumes, of course, that any machine may safely withstand dead short circuit at its own terminals.

It is of interest to note that the lower the inherent reactance of the generators the lower will be the value of Z_K, and for purposes of easy distribution of load between the several generators when the load decreases and one or more generators are taken off the line a low value of Z_K will cause either the voltage on the feeder bus now not fed directly by a generator to fall, or the power factor of the load taken from this feeder bus to be changed. For the best distribution of load and the most nearly constant value of voltage at different feeder buses, the lower Z_K is, the better.

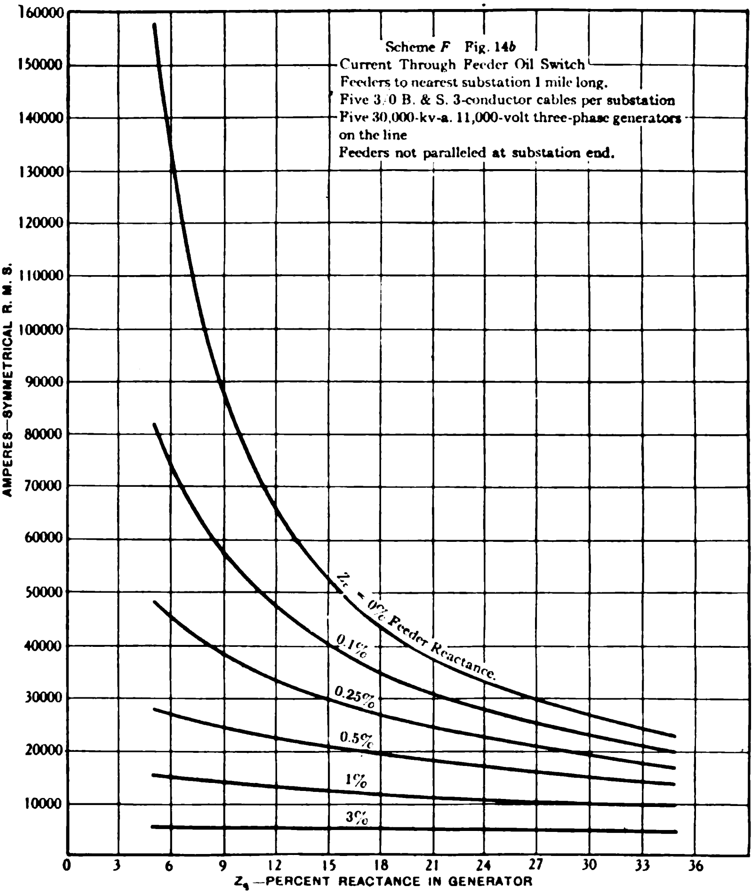


Fig. 25

To compare this scheme, *S*-1, of using feeder bus reactances and synchronizing reactance, with feeder reactance, scheme *F*, shown in Fig. 14*b*, and with bus reactance, scheme *B*, shown in Fig. 14*c*, the curves of Figs. 25, 26 and 27 have been computed. The same system of five 30,000-kv-a. 11,000-volt generators has been assumed.

From Fig. 26 it is seen that with generators having a 5 per cent reactance, a feeder reactance of 1 and 1.5 per cent reduces the current to values of 15,500 and 10,000 amperes respectively, and further it is clear that nearly the entire drop occurs in the feeder reactance, especially when the generator reactance is low. There are, however, two disadvantages of this scheme:

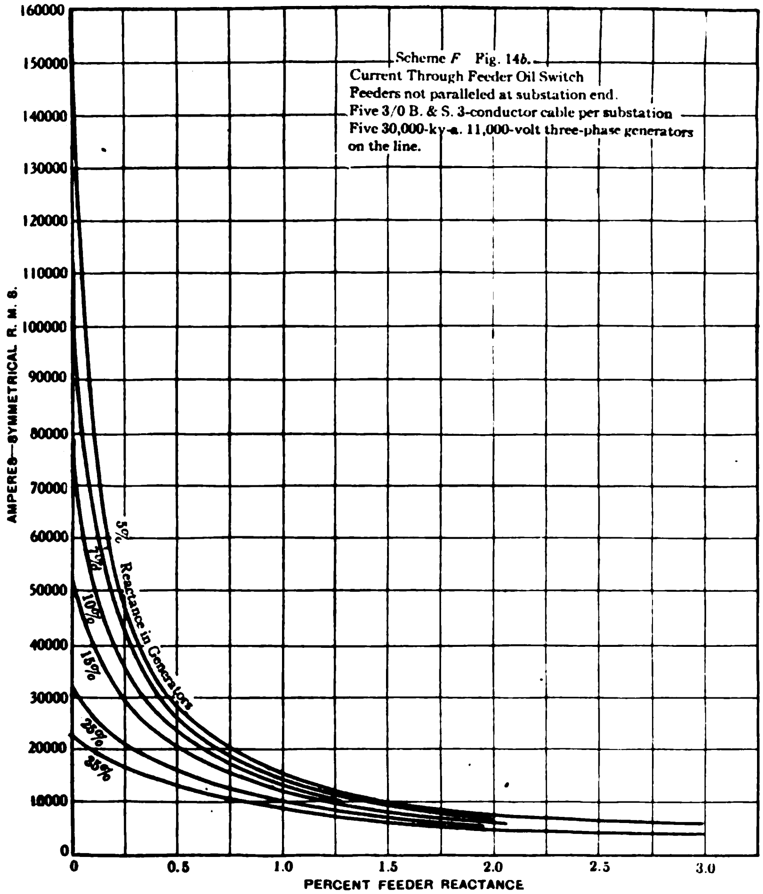


FIG. 26

1. When a short circuit occurs on the bus, the current flow becomes enormous; the bus voltage drops to zero and all synchron-

ous apparatus is certain to drop out of step if the trouble is not instantly cleared.

2. When a machine is put on the line out of phase, there is no means of limiting the current in the synchronizing circuit. (See Fig. 29). Both of these objections may be overcome in scheme *S*-1. The advantage of this scheme *F* is that when trouble occurs outside the feeder oil switch the trouble is localized in the feeder experiencing conditions and may be quietly cleared from the line, without a shock to the entire system.

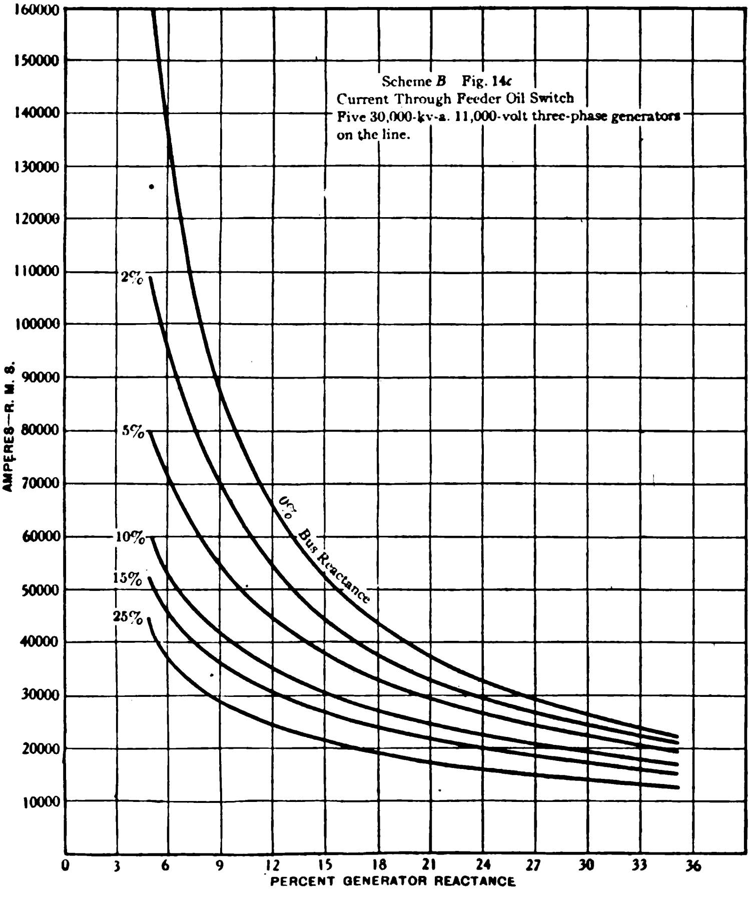


Fig. 27

Bus reactance as shown in scheme *B* is analyzed graphically in Fig. 27. Suppose, for example, it is desired to limit the short-circuit current on a feeder to 25,000 amperes. This can be done in scheme *B* by using generators have 12 per cent reactance, and bus reactances between machines of 25 per cent. In scheme *S*-1 this can be accomplished by a generator reactance of 7 per cent, a feeder bus reactance of about 4 per cent and a synchronizing reactance of 2 per cent. Should the trouble occur on the synchronizing bus in scheme *S*-1, the current would rise to 87,500

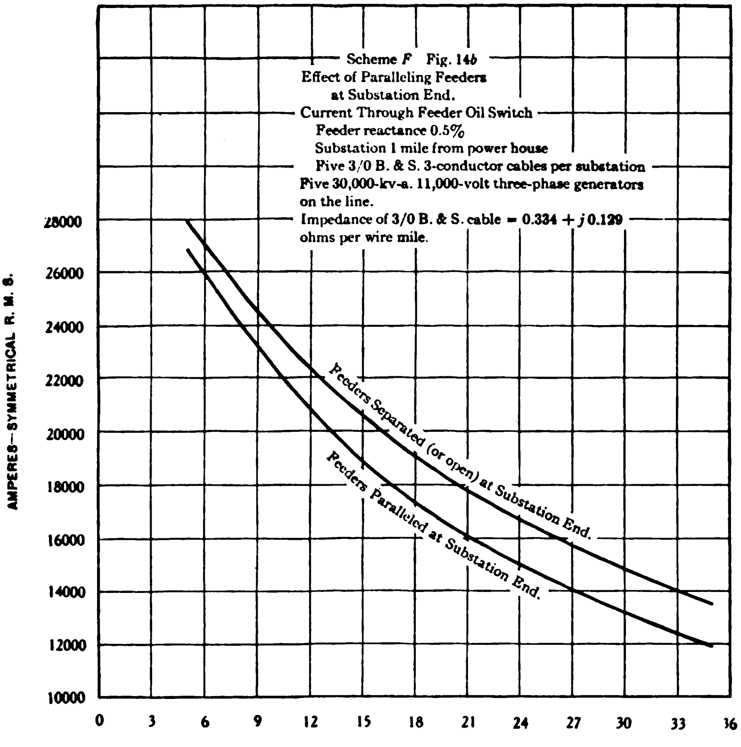


FIG. 28

amperes (Fig: 22); but this current would not pass through any one oil switch or small cross-section cable. The maximum current obtainable by the use of bus reactance would in this case be 25,000 amperes. Thus, the busbar reactance scheme reduces the short-circuit current to a low value, but at the expense of a large reactance in the circuit.

Another disadvantage of busbar reactance is that under certain conditions of operation it would be necessary to feed through four of the bus reactances, thus producing considerable difference of voltage along the bus. Scheme *S*-1 with its 7, 4 and 2 per cent reactance would be little affected by drop in voltage from one feeder bus to another.

EFFECT OF PARALLELING FEEDERS AT THE SUBSTATION END

In scheme *F*, it is interesting to note (from Fig. 28) that the short-circuit current through the power house feeder oil switch is less when the feeders are paralleled at the substation end than when opened. This at first seems surprising, but on analysis the reason is obvious. The kilovolt-ampere output of the generators is greater when the feeders are paralleled at the substation end since the path of one feeder reactance in parallel with other circuits to the substation end of the affected feeder and back to the points of short circuit is less than the impedance of one feeder reactance alone. Therefore the current output of the generators

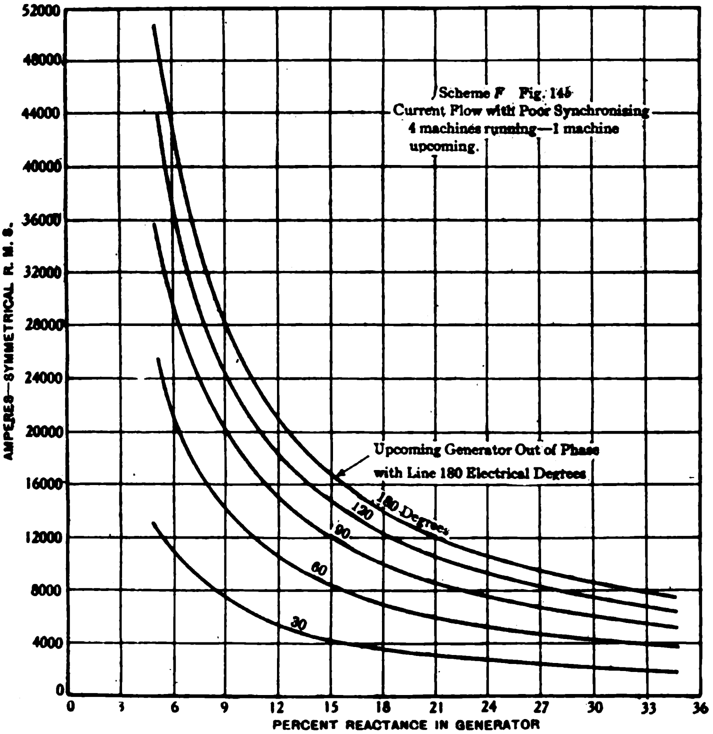


FIG. 29

is greater, and this current flowing through the generator reactance gives a lower bus voltage than when the feeders are not paralleled at the substation. This lower bus voltage impressed across the given feeder reactance therefore produces less current through the feeder oil switch. And if the breaking capacity of the oil switch or heating of the cables are the limiting features of the system, better results can be obtained by paralleling the feeders at the substation than by leaving them open, in scheme *F*.

A word of warning should be given in using the expression

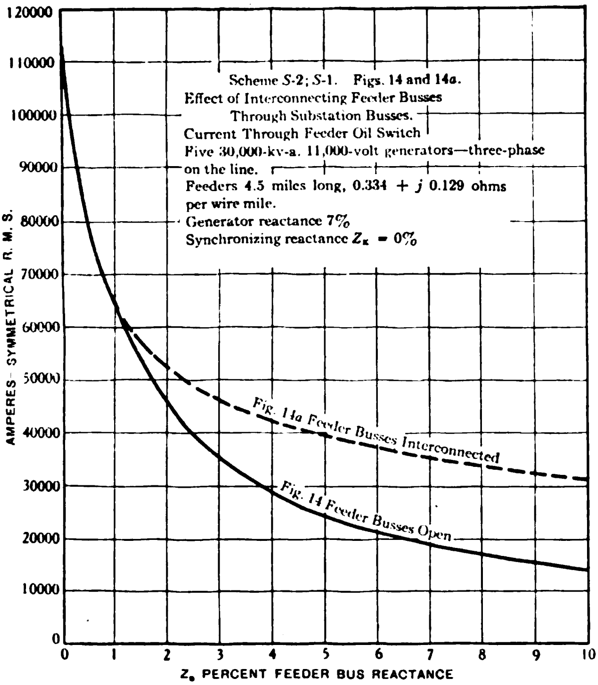


FIG. 30

"kilovolt-amperes generated at short-circuit;" for, as above shown, the strain on the feeder is less as the kilovolt-amperes generated at instant of short circuit is increased.

In scheme *S*-2 great flexibility of operation can be gained by running, to any one substation, feeders from each separate feeder bus. If one bus is now in trouble due to short circuit it is possible by the use of selective relays to clear that feeder bus of feeders, and by this arrangement any substation will lose only one feeder. A substation having five feeders, for example, one to each feeder bus, will lose 20 per cent of its cables, thus imposing 125 per cent load on the remaining cables. In this way service would continue on the system uninterrupted.

Under short-circuit conditions (scheme *S*-2, Fig. 14*a*), however, the current is very much increased, as is shown by the curves of Figs. 30 and 31. It is clear, that if it is necessary to limit the short-circuit current in a feeder to 30,000 amperes, it is impossible to interconnect the feeder buses through substation feeders, as in Fig. 14*a*, with any reasonable value of Z_B, (machines assumed to have 7 per cent reactance).

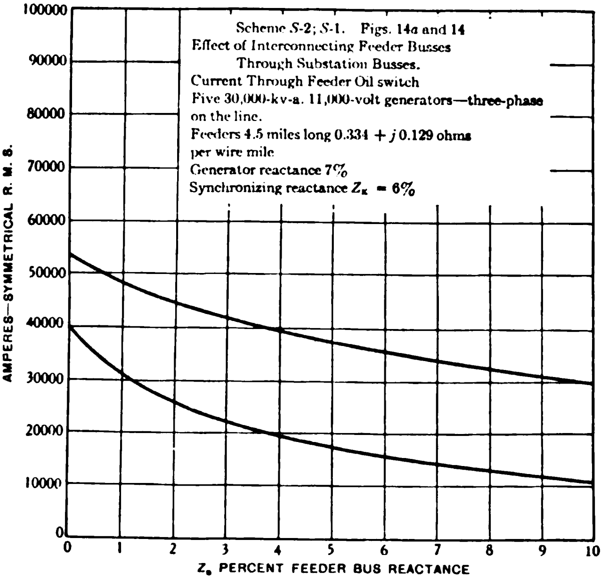


FIG. 31

Another advantage of these schemes *S*-1 and *S*-2, as here presented, is that very low reactance can be used in the generator, in fact as low as mechanical protection to the generator itself justifies. The lower the generator reactance, the higher Z_B can become for a given reactance in the path of direct feed from generator to feeder bus, and the higher will be the bus voltage on the unaffected feeder buses. This results in less possibility of synchronous apparatus dropping out of step at the instant of short circuit.

SUMMARY AND CONCLUSIONS

It has been shown in this paper that the average mechanical forces existing between conductors of a three-phase cable carrying short-circuit currents, and between busbars, rise to relatively high values at the instant of trouble. These forces can be reduced in cables by either limiting the current or increasing the distance between conductors. The same applies to busbars, and in addition, the position of the busbars can be adjusted by placing them in the same plane so that the mechanical forces may be considerably reduced.

The heating of cables may be the limiting feature in controlling short-circuit current, since it is quite possible for the temperature of the conductor to rise to such a point as to endanger the insulation of the cable even in the very short time that it takes an oil switch to operate after the short circuit has occurred. With the characteristics of the generators under short-circuit conditions known, it is possible to compute the temperature rise, even although the current is of transient character.

In using reactors to limit the current flow on a power system, the method of plain feeder reactance is not fully effective, as trouble on the main station bus is almost certain to cause to drop out of step all synchronous apparatus on the system. Further, this method offers no protection to machines against poor synchronizing.

Station busbar reactance is effective under short-circuit conditions, but under normal operation is objectionable on account of the large voltage drop in transmitting power from one end of the bus to the other.

The scheme of feeding from the machine terminals, and paralleling generators on a separate bus, as brought to light by Mr. Stott, is extremely flexible and very effective in furnishing protection. It can limit the current to a safe value without an excessive amount of reactance in the circuit; it can protect the machines against mechanical injury due to poor synchronizing; and can transmit power from between different points of the bus with far less voltage drop than with the bus reactance scheme. It makes possible the use of generators having a low inherent reactance, provided, of course, the machine is designed to withstand dead short circuit at its terminals. Further, the lower the reactance of the generator the less possibility there is of the synchronous apparatus on the system dropping out of step due to reduced power house voltage.

The possibilities of this system are as yet probably not fully realized.

DISCUSSION ON "VOLTAGE TESTING OF CABLES" (MIDDLETON AND DAWES), DETROIT, MICH., JUNE 25, 1914. (SEE PROCEEDINGS FOR JUNE, 1914.)

(Subject to final revision for the Transactions.)

W. A. Del Mar: The factor of safety of an insulated wire or cable, being the ratio of the breakdown voltage to the normal operating voltage, cannot be determined experimentally without testing the insulation to destruction. It can, therefore, never be definitely known in practise, although susceptible of approximate predetermination in the absence of faults, by calculation based upon tests. If, however, we define the *factor of assurance** of an insulated wire or cable as the ratio of the test voltage to the normal operating voltage, we can provide an experimental basis for the comparison of voltage tests. Thus, if a cable for operation at 11,000 volts is tested at 25,000 volts, we have a factor of assurance of 2.27. If the breakdown voltage is 75,000 volts, the factor of safety is 6.82, and the ratio between the safety factor and the factor of assurance is 3.0.

Two principles are now contending for recognition in the standardization of voltage tests. One is that insulated wires and cables should be tested to give a fixed factor of assurance, and the other that they should be tested to as high a voltage as they will stand without injury to any part of the insulation which may be free from defects. The latter principle is equivalent to a fixed and small ratio between the factor of safety and the factor of assurance.

Mr. Middleton recommends the latter principle, and I believe that he is right for the following reason: If a defect exists in the insulation of a wire or cable it may not be revealed by a test voltage two or three times the working voltage, but may cause a breakdown in service after the cable has been subjected to the strains of installation and operation. Hence a test which provides an apparently ample factor of assurance may not be sufficiently severe to assure the greatest reliability of operation. If, on the other hand, the breakdown voltage is calculated from the known dielectric strength of the insulation, a test voltage can also be calculated which will eliminate defects without injuring those parts of the insulation which are free from defects.

At high voltages, these two principles lead to the same results, as the thickness of insulation is usually proportioned to give a reasonable factor of assurance.

Working on the principle outlined above, the Wire and Cable Committee of the Association of Railway Electrical Engineers arrived at the following test voltages, which are somewhat lower than these given by Mr. Middleton. These test voltages are given in Tables I and II and Fig. 1, herewith. The difference may be partly due to the fact that most of the manufacturers have testing generators with less perfect characteristics than the one described in the paper under discussion.

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*Proposed by Mr. F. J. White and incorporated in Standardization Rules of A. I. E. E., 1914.

The voltages in Table I were calculated by a formula similar to Mr. Middleton's except that the effective thickness of insulation was assumed to be slightly less than the nominal thickness, due to irregularities in manufacture and installation. An example of the former type of irregularity is the eccentricity of the insulation with respect to the wire, and of the latter, the reduction of insulation thickness on the outside of bends.

TABLE I.

TEST VOLTAGES, KILOVOLTS

FIVE MINUTE TESTS

30 per cent *Hevea* Rubber Compound—Use 100 per cent of following voltages. Varnished Cloth—Use 75 per cent of following voltages. Impregnated Paper—Use 75 per cent of following voltages.

Size of Conductors.	Thickness of Insulation, 64th Inch.							
	2	3	4	5	6	7	8	10
18 A. W. G.	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5
16	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5
14		2.5	5.0	6.0	7.0	8.0	9.0	11.0
12		2.5	5.0	6.0	7.5	8.5	9.5	11.5
10		3.0	5.0	6.5	8.0	8.5	10.0	12.0
8		3.0	5.0	7.0	8.0	9.5	11.0	13.0
6			5.0	6.5	8.5	10.0	11.5	14.0
4			4.5	6.5	8.5	10.0	11.5	14.5
2			4.0	6.0	8.0	10.0	12.0	15.0
1			4.0	6.0	8.0	10.0	12.0	15.5
0				5.5	8.0	10.0	12.0	15.5
00				5.0	7.5	9.5	11.5	15.5
000				5.0	7.5	9.5	11.5	15.5
0000				4.5	7.0	9.0	11.5	15.5
250,000 cir. mils				4.0	6.5	9.0	11.0	15.5
500,000				2.5	5.0	7.5	10.0	14.5
750,000						6.5	9.0	14.0
1,000,000						5.5	8.0	13.0
1,250,000							7.5	12.5
1,500,000							7.0	12.0
1,750,000							6.5	11.5
2,000,000							5.0	10.5

(For intermediate sizes use the voltages corresponding to the next larger size, having the same thickness of insulation.)

TABLE II.

TEST VOLTAGES, KILOVOLTS

		Thickness of Insulation, 64ths Inch.								
		12	14	16	18	20	22	24	26	28
6-5 A. w. g.	Rubber	16	18	20	22	23	25	26	28	29
	V. C. or Paper	15	17	19	21	23	26	28	30	31
4-2 A. w. g.	Rubber	17	19	22	24	25	26	28	29	30
	V. C. or Paper	15	17	20	23	25	28	30	32	34
1-0000 A. w. g.	Rubber	18	21	23	25	27	28	30	31	32
	V. C. or Paper	16	19	22	24	27	30	32	34	36
250,000 cir. mils	Rubber	19	22	24	26	28	30	31	33	34
and larger	V. C. or Paper	17	20	23	25	28	31	33	36	38

While the logarithmic formula is useful in calculating the test voltage for a given size of conductor and thickness of insulation, it is dangerous for calculating the thickness of insulation for a given working voltage, as mechanical considerations generally dictate the use of more insulation at low voltages than is indicated by considerations of dielectric stresses. The requirements of the National Electrical Code for wire insulated for 0 to 600 volts represent the results of experience as to the minimum thickness of insulation which has been found necessary in practise. The thickness should seldom be less than required by the Code and should sometimes be more, regardless of voltage.

It should be noted that the formulas given in this paper do not take into account the difference in dielectric stress due to the size of strands in the cable. This has been treated by Prof. Levi-Civita in a paper by E. Jona in the Transactions of the International Electrical Congress, 1904. It would be interesting to hear whether Mr. Middleton's experiments agree with Prof. Levi-Civita's calculations.

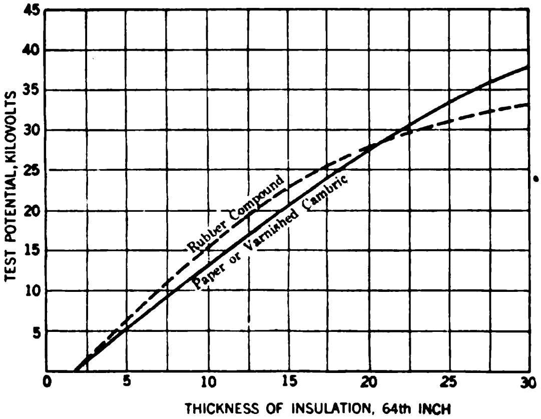

FIG. 1

I regard the paper by Messrs. Middleton and Dawes as one of the most important that has ever appeared on this important subject and believe that it will exert a strong influence in the rational standardization of voltage tests of wires and cables.

C. O. Mailloux: On the second page the authors speak of paper as an insulation for wires and cables. There is a third method of making high-tension cables, which consists in wrapping the conductor with a previously prepared paper. The paper, which is first treated with an insulating compound, is wrapped into rolls; and then the conductor strand from which the cable is to be made is wrapped around with this treated paper to the proper thickness, after which the cable covering is placed on the whole. The cable is then submitted at once to the proper test. The process is shorter and simpler, and less expensive than the other processes of preparing the cables with dry paper, subjecting them to a vacuum, and then treating them with compound. There is an English firm which makes high-tension cables according to that process. I understand they have given satisfactory results, though I am not informed as to the comparative results. It would seem that if the method lends itself to the preparation of insulated cables for high tensions, and if such cables can withstand high tensions, the process would have some advantages: One could make sure more easily that every portion of the insulating material would be properly treated with the compound, and also that all of the defective parts of the insulated paper were eliminated or removed. On the other hand, there is the difficulty resulting from the possibility of entrained moisture at the time of laying the insulating paper around the conductor. It would seem very difficult, in an ordinary atmosphere, to keep out dust and also moisture, so that, as the insulated paper is wrapped around the conductor, one might easily understand that there would be air bubbles, particles of dust, and particles of moisture imprisoned in the cable, whereby the quality and the durability of the insulation would be impaired.

Henry G. Stott: I was about to call attention to the point that Mr. Del Mar brought up in his discussion, which is that it may be open to inference from the statement here that if there is a large diameter, it would be feasible to reduce the thickness of the insulation. I do not think the authors desire to convey that idea, but it may be drawn as an inference from this paper that it could be done. From a purely electrical standpoint it could, but from a mechanical standpoint we must have heavier insulation with a large conductor than with a small conductor. That should be emphasized, as some might take advantage of the curve to say that they could reduce the insulation on 500,000-cir. mil cable, but if they did so, they would get into trouble later on.

On page 995, at the bottom of the page, is a paragraph on over-stressing cables. That is a point we have heard a great deal about in the last fifteen or twenty years. We have had in use now several hundred miles of cable over 15 years. These are all high-tension cables, and they are put under tests at 2.5 times working potential once a year. There is not the slightest sign of deterioration in the cable, after fifteen years' use. In fact, some of these cables were originally designed for use on 6600 volts, and are now being used on 11,000 volts, and in spite of this we have had this 2.5 times pressure test on them once every year, and many of them have had it as many as eight or ten times a year, due to cable changes, etc. Each time the cable is cut for any purpose, it receives the breakdown test, and once a year on general principles it receives a breakdown test.

We should prefer to have the cable break down on test, rather than in practical operation. While theoretically there may be some result of over-stressing of cables, yet practically, based on fifteen years' experience, with many hundreds of miles of cables, we have not yet found that to be so.

E. E. F. Creighton: I should like to ask Mr. Middleton something of the theories—he said there were many—to explain why a short piece of cable will stand so much more potential than a longer piece.

Charles L. Fortescue: I want to call attention to the very common mistake in attributing the third harmonic distortion of the transformer to the hysteresis. The distortion in the transformer is directly due to the cyclic variation in permeance, a small part of which is caused by hysteresis. Hysteresis produces no distortion.

In connection with the proposed method of measuring maximum voltage of high potential, Mr. Chubb and I at last year's mid-winter convention described a method of measuring the maximum value of the wave on the high-tension side, using a condenser. The average value of the charging current of the condenser across which high voltage is impressed is directly proportional to the product of the maximum voltage and the frequency of the impressed wave. This is a very simple way of measuring the maximum value, and it is quite reliable. I do not think a method of measuring the maximum value of the wave which requires a voltage transformer is reliable. The fact that a sine wave generator is used does not prevent third harmonic distortion in the step-down transformer itself, which, due to its distributed capacity and inductance, may be quite large.

The third harmonic distortion due to the step-up transformer will also be enhanced when transformed by the step-down transformer, so that as a means of measuring the maximum of the secondary voltage of the step-up transformer the proposed method will not lead to correct values. It is better to measure the maximum value directly by the method we have described or else by some modification, such as that described by Dr. Whitehead in his paper presented yesterday (*The Electric Strength of Air—V*).

Some question has been raised as to why long cables break down on test more easily than short cables. I think this is due to the combined effect of the distributed capacity and self-induction of the cable. When the voltage is supplied to the end of the cable, which is usually coiled on a spool, the actual average voltage in the cable, in the case of a long cable, is much higher than the voltage at the end, due to the effect of distributed capacity and inductance. It may, in long cables, be 15 or 20 per cent higher at the end of the cable than at the point where the voltage is applied. I think this may possibly be the reason why a long cable breaks down more easily than a short cable.

Percy H. Thomas: I will ask Mr. Middleton a question. He has discussed the effect of the third and other harmonics on the maximum voltage which may be impressed on a cable. It occurs to me that there is another effect of the high frequency which may possibly be important, and that is its heating effect. The insulation of an underground cable is stressed very high. The alternating electric stress causes a certain amount of heating within the material. That heating at 60 cycles, we will say, is almost negligible. At 180 cycles, or 200 or 300 cycles, that heating may be very important. A third harmonic, or fifth harmonic, so located with regard to the fundamental as to reduce the voltage peak, might develop heat enough within the dielectric, especially at any peak point, to raise the temperature to the puncturing point. I would like to know if anything has been done along that line of investigation.

The other question is about the puzzling fact that a long cable apparently breaks down at a lower voltage than a short cable. I would like to see two tests made, one with an outfit such as described by Mr. Middleton, comparing a long length with a short length cable, and a second test comparing a long length with a short length of cable, made according to Mr. Stott's generator method. Tested by the former method, you might find a marked difference between the voltage of failure in the short and long length of cable. Tested by the large generator, on the other hand, you might find there was not so much difference. This matter of the distortion of the wave by the large charging current of the long cable with the possible introduction or magnification of the high-frequency harmonics, may mean that there is produced a high-frequency effect in the test of the long cable, which does not exist with the short cable.

J. R. Craighead: In respect to obtaining a voltage supply, a generator which gives a sine wave is the most satisfactory, provided it will maintain the sine wave under testing conditions, but as the author states, those generators are rather rare, especially when loaded on a capacity load of pretty near their limit.

There is an alternative way which consists in using any ordinary line potential of a normal commercial wave form, and with a sufficient power, so that the capacity effect on the line wave is absolutely negligible. If this is taken through a transforming outfit of considerable reactance, it is not difficult to obtain a wave which more closely approaches a sine than the line wave itself. This was tried out to some extent in the high-potential testing of large turbine generators, obtaining by the oscillograph the wave forms on the high-and low-tension sides of the step-up transformer, and also the line wave, back of the regulating apparatus. For most large capacities it is not very difficult to get the correct amount of reactance so that the wave form across the machine under test is satisfactory.

In regard to the voltmeter described, the use of the oscillograph for this purpose was described and the suggestion of an elementary oscillograph-voltmeter was made in a paper by Mr. L. T. Robinson and Mr. J. D. Ball presented two years ago at the Boston convention, entitled *Permeability Measurements with Alternating Current.*

W. I. Middleton: The point brought up by Mr. Stott and Mr. Del Mar is very well taken. We should possibly have mentioned the fact that we could not depart from the Underwriters' specification. We realize that the heavy conductor does require a thicker wall of insulation for mechanical purposes, and that we did not mention this specifically, was an oversight on our part.

In regard to the long and short lengths of cable, and the difference in their ability to withstand voltage strain and test, I too am looking for information. We had an interesting paper in New York last winter on the testing of cambric insulation with different size electrodes, and I must say that Mr. Farmer's experience with electrodes bears out my experience with the long and short lengths of cable. Further, some time ago there was a paper written, I think by Mr. Moody, on some corona tests, and it was then found that, with a short length of bare wire, corona started at a much higher voltage than it did with a long length. So apparently the same phenomenon occurs here as in other insulating materials, which, to my belief, breaks down the law of probability.

Mr. Thomas spoke about the long and short lengths of cable and also mentioned the effect of heating. We have tried to be very careful about this matter of heating, and so have recommended short period testing. Many tests require only one minute. We usually ask for five-minute tests, as we believe that this eliminates the question of heat. Then, again, these cables are generally submerged in water when they are under test, and the question of heating, under those circumstances, I believe, is almost entirely eliminated.

When a long time test is attempted a multitude of different factors are encountered, and the effect of ozone generated at the ends of the cable, which attacks the rubber insulation, gives rise to a lot of theories regarding the piling up of voltage on the ends of the cable, etc. We have tried to eliminate these factors in our regular practise, realizing that we are obliged to make many tests in the course of the day, and all of this work is carried out on commercial lengths of cable, as they pass through the test room of the factory.

Chester L. Dawes: In regard to Mr. Stott's remark as to the application of this formula to the calculation of the wall of the insulation, mechanical as well as electrical considerations must necessarily be taken into account. When the cable is once designed, the wall being of the proper thickness to take care of the mechanical and electrical stresses to which it will be subjected in service, the test voltage should be determined by this formula or one that is its equivalent, in order to be certain of breaking down any defects which may exist in the insulation.

As to Mr. Fortescue's remarks, I agree with him that the third harmonic is also due to changing permeability, but hysteresis necessarily represents changing permeability. If the iron could operate without hysteresis, the third harmonic might yet be present, of course.

The method which he suggests for measuring the peak voltage I admit is correct, but it must be remembered that a device to be used in the test room should be direct-reading and capable of being used and used rapidly by a testing room employee.

Referring to the distortion of the voltage wave through the potential transformer, we took one oscillogram on the primary of the step-up transformer, and another one on the secondary of the potential transformer, thus stepping-up and stepping-down, and we could discern no difference in the oscillograms.

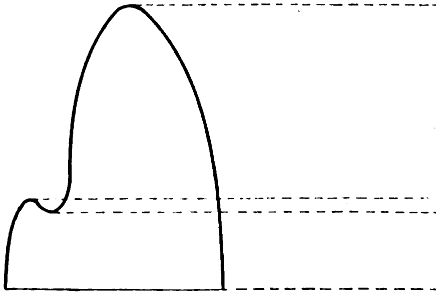

FIG. 2

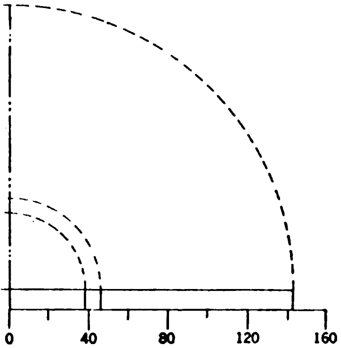

FIG. 3

We had a very distorted wave under these conditions. Frequently we have looked into the oscillograph, without taking records, and have never been able to discover any difference between the wave form on the primary and that taken from the potential transformer secondary.

To have the voltage pile up in a long length of cable, inductance must be present. When the cable is installed, the inductance is very small, and, therefore, the probability of the voltage piling up is very slight.

In regard to Mr. Craighead's suggestion as to obtaining a sine wave with reactance, I assume that he means connecting the reactance in series with the transformer primary. This method could not be used in the test room, because it is too unstable a combination; and the operator would not readily understand how to adjust for a sine wave under each set of conditions. Further, resonance difficulties would be experienced, that is, the circuit might become sharply tuned, and a high voltage might suddenly pile up on the cable. As I have just stated, it is necessary to have a method of measuring the peak voltage which the ordinary switchboard operator can understand and easily manipulate.

As to the voltmeter, I may add that a general idea of the wave form is obtained by observing the band of light. For instance, with a wave of the type shown in Fig. 2 (many of this type are shown in the oscillograms) the light on the scale will have the general appearance shown in Fig. 3. The light at the points corresponding to the lower peak and to the depression will be more intense than it is at other parts of the scale. In the same way, a flat-topped wave shows a much more intense light at the end of the scale than a peaked wave does. Similarly the tooth ripples are readily discerned.

DISCUSSION ON "METHODS OF KEEPING DOWN PEAKS ON POWER PURCHASED ON A PEAK BASIS" (TYNES), DETROIT, MICH., JUNE 23, 1914. (SEE PROCEEDINGS FOR JUNE, 1914.)

(*Subject to final revision for the Transactions.*)

Rudolph Tschentscher: Power contracts, as you all know, are usually made on a peak basis, and the question of the reduction of these peaks is a most important one. I believe it is desirable to emphasize the point Mr. Tynes has mentioned, namely, that the reduction of peaks is of material benefit to the power generating company.

Paul M. Lincoln: This point that Mr. Tynes has raised is an exceedingly important one. Wherever power is taken from a hydraulic plant, the maximum demand method of charging is a logical one; no question about it. This is particularly true in the case of the hydroelectric plant where the water is not limited, such as the Niagara Falls plant. It does not matter to the power company whether the power is taken for 15 minutes, or one minute a day, or for the 24 hours continuously, it is the maximum demand which dictates the amount of the power bill, because the ability of the power company to supply power is limited by the output of the prime mover or of the generator. The fact that the power is taken continuously 24 hours a day merely means that the water is running through the wheels for that length of time, instead of running over the spillway. It is therefore perfectly logical for the power company to insist upon a system of selling on the maximum demand basis.

In the case of the steel company which Mr. Tynes represents, its power curve is anything but an even line of continuous demand. It also has its own apparatus for generating power, and his problem has been to so regulate his apparatus as to make the power taken from the power company show an even line, to so regulate his own apparatus that all of the excess above that even line is taken from his own steam plant. The method which he has used to secure that result is exceedingly interesting, and one of very great value.

J. Lester Woodbridge: This paper presents a special solution of a problem which undoubtedly exists very commonly in districts where power is purchased on the maximum demand basis. It would, perhaps, be interesting to compare the results obtained by this solution with those which might have been obtained by the application of a storage battery, but the data given in the paper are hardly sufficient to permit of such a comparison being made. Doubtless the solution adopted in this particular case was the wise one in view of the presence of exhaust steam which, I presume, was obtained without additional cost. The paper, however, does not give us the length or the height of the peak very definitely.

It would be interesting to have the financial results set forth in this paper as well as the technical results; for example, whether the operation of this turbine actually costs anything for fuel, that is, whether the steam was supplied without additional cost for fuel, whether the exhaust steam was sufficient to operate the turbine, or whether some live steam had to be used; also whether the cost of attendance was increased. In fact, the total cost of operating the plant would be an interesting item, so that we might compare that with the saving effected. Possibly these figures might be added by the author in a subsequent discussion.

It would also be interesting to know the total power produced by the mixed turbine and the cost per kilowatt-hour to produce it. It also occurs to me to ask whether, if the power is obtained without cost by utilizing exhaust steam, the investment for the installation having once been made, it would be economical to operate this outfit to handle more than merely the peak load? Could it be operated 24 hours a day to take some of the body of the load itself, if it does not cost anything to operate? A number of these questions could perhaps be very interestingly discussed in an addition to the paper.

J. R. Bibbins: Considering this paper from the standpoint of the central station, I notice from Fig. 4 that a one-minute maximum is the basis upon which this system depends. It seems to me that the economic value of this whole peak-reducing apparatus depends greatly upon what duration of the peak is incorporated in the power contract. I have in mind a railway load in which the maximum demand is over **100,000** kw. The power contract involves a fixed rate primary or readiness-to-serve charge, proportioned to the maximum demand of an hour's duration (averaged over three successive days), and a secondary or service charge, dependent upon the output of the station, and with a sliding scale of rates per kilowatt-hour. This works out as follows: During the summer the maximum peak loads are very largely reduced, but the railway company continues paying for the maximum one-hour demand of the previous winter, and logically so, throughout the entire year. If a mild winter happens to occur, in which the heating and the additional friction load is reduced, these two factors combine to reduce the maximum peak and primary charge.

Now, the point that interests me here is the use of this one-minute maximum, and if we analyze a railway load it is very clear that the actual peak upon which such a primary charge depends is not always of as long duration as stated in this contract, *i.e.*, one hour. And so it occurs to me that there is a possibility of applying a shorter maximum period in power contracts for such large systems with primary charge adjusted in accordance with the relative overload capacity of the station. Referring back to the prime mover, it is very clear that, with the very large units now used and the great overload capacity available within reasonable limits of temperature rise, if we had a shorter maximum period than one hour the primary charge upon which it is computed might be considerably less than it is to-day.

In this particular case the contract worked out in a very peculiar way. As the system expanded and the power load built up, it was found that the primary charge kept ahead of the secondary charge, with the net result that the total cost per kilowatt-hour actually increased as the power consumption of the railway increased. It seems rather illogical that with a load increasing from 60,000 to 100,000 kw. the net cost of power per kilowatt-hour, including these two factors, primary and secondary, should have risen under conditions of such an extremely large output. One explanation will occur, from the fact that any considerable improvement in the service of street railways necessarily means more service at rush hours. In fact, the street railway problem is almost entirely one of rush hours, and the additional equipment operated at the rush hours must necessarily increase the maximum demand for that period. So that as we demand from our street railway companies improved service, we must suffer a decrease in load factor and a higher primary charge.

I take it that from the prime mover end, there is little hope for the development of a special type of apparatus, other than the turbo-generator outfits that we already have, which would automatically absorb these high peaks, with the single exception of the combined hydraulic and steam power system which Mr. Lincoln mentioned.

So the specific question I raise, from the central station standpoint, is, whether this shorter period mentioned in this paper would not be equally as applicable to central station conditions as to the industrial load that is here described, *i.e.*, whether a one-hour maximum is entirely justifiable in cases where the real maximum for which the central station must provide apparatus is considerably less than one hour; in other words, whether we cannot take advantage of that fact and reach a more logical primary charge, so that the occurrence of a very short peak load occasionally, of considerably higher maximum than the hour would average, (but well within the momentary capacity of the equipment), will not become such a burden as it does in this case. Obviously, the shorter the duration of peak, the greater the margin of safe overload available from a given investment, and usually, in railway loads, the exaggerated peaks are of very short duration.

R. H. McLain: I would like to say a word about this matter of charging for peaks, based on one example that I am familiar with. There is a large number of coal docks and a street car load, all of which make up a very large part of the central station power load, and there was, before many coal docks began to buy power, a great deal of argument about how to charge for this power. In the beginning, the coal docks were charged on an instantaneous peak basis—that was the primary charge for them. As the coal docks increased in number, the load curve for the central station company became flatter and flatter. I do not know how they charge for the power now, but I know enough about the system to know that it would be practicable for them to charge for five-minute peaks, or some other peak like that, and not take any account whatsoever of these one-second and one-minute peaks. I think that the central station companies should take a very broad-minded view of this situation, and when they serve a lot of power consumers should try to keep from putting the customer to a great deal of expense in cutting down his peak, when another customer across the road, or two or three more, might combine with this first customer in such a way as to make the entire load almost uniform. I firmly believe that the more the central station companies take this view into account in making their charges, the more popular will be the use of central station power; but, of course, for any one location the particular nature of the load should be taken into account.

E. D. Dreyfus: The ingenious method employed by Mr. Tynes to maintain a practically uniform load upon the power company's system has impressed me very much. No doubt Mr. Tynes has been able to effect a certain degree of economy in the operation of his plant which is probably due to fortuitous conditions such as the availability of an exhaust steam supply and the presence of operatives who can well afford to take care of the extra equipment necessary in addition to looking after their other duties. The situation is manifestly exceptional and therefore we should be careful that the idea does not become prevalent that the scheme described is possible of broad application.

According to my conception of the problem and from many investigations made in this direction, the trend of results tends to show that it is the low load factor business upon which the central station can most readily compete with the isolated plant. This is largely true for the reason that the so-called "stand-by" cost of the isolated plant (including capital charges, labor, banking and discrepancies) plays an important part in the total cost under low load factor conditions.

When operating at high load factors, these "stand-by" charges are spread over a large number of kilowatt-hours and therefore the unit cost is very rapidly reduced. I believe this can best be shown diagrammatically, and the accompanying illustration (Fig. 1), in which values are taken from a case selected at randon, will aid in establishing the truth of the proposition.

Obviously the comparative showing will in each case depend upon the assumptions made. There is a wide range in the operating results of different isolated power plants, naturally depending upon their equipment and the ability and faithfulness of the operating force. Two limits (one shown by heavy solid lines and the other by heavy dotted lines) for the isolated power plant operation are given so that this phase may be duly regarded. On the other hand, the cost of central station power for fixed conditions is fairly uniform in the different geographical divisions of the country, and consequently a single line of costs has been included for central station power (shown by the heavy dot and dash line).

Hence, due to what may be termed the inherent slope of the total cost lines or curves, the relative rise with load is actually in favor of the isolated power plant, and, as here indicated, the larger independent plant may show lower costs at points beyond 50 to 75 per cent load factor, provided all other handicaps have been overcome. While this argument is of a general nature it is sufficiently specific, I believe, to prove that unless the peak can be reduced by flywheel effect or by virtue of

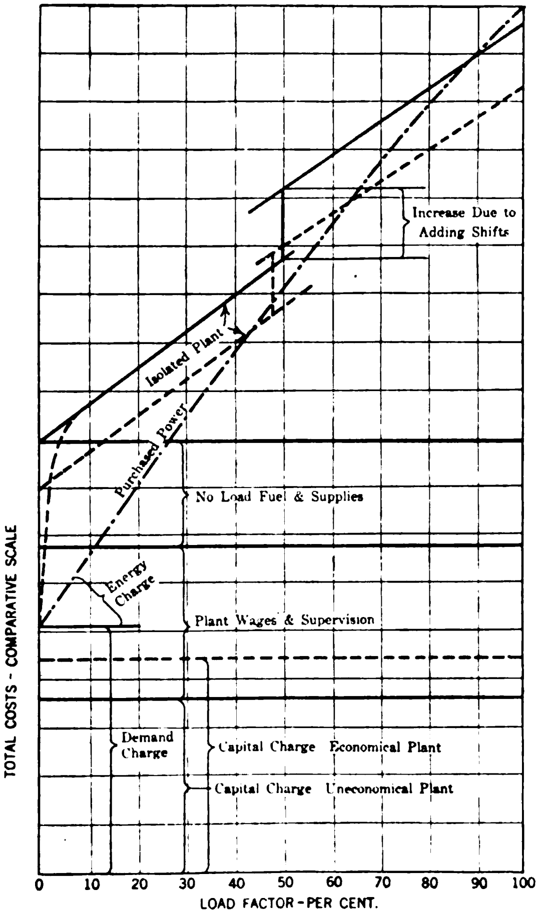

FIG. 1

some peculiar local conditions, the cost of attempting it can hardly be justified.

The large and increasing number of industries committed to the use of purchased power, and representing over 33 1/3 per cent of the electric power used in the manufacturing industries in the United States, prompts the exposition of these facts not only to confirm that "out-and-out" purchase is usually the most profitable course, but also to obviate any impression that economical peak reduction methods are readily put into practise as a general proposition.

The load factor of the majority of industrial plants is considerably less than 30 per cent and but few exceed 60 per cent, and as a rule it may be said that the power system can best carry the whole burden of the consumer's load.

As power is ordinarily only a small percentage of the total cost of production in the average industry—usually less than 10 per cent—the refinement in operation as discussed is correspondingly reduced in importance. Moreover, the factory and mill manager of the present day is exhibiting a marked tendency toward having his plant stripped of all machinery and equipment non-essential in the conversion of the raw materials into the finished products, reserving all funds and employment to that purpose only.

In concluding I wish to say that the paper under discussion is of a great deal of interest technically and in relation to a few isolated cases, but the commercial import is rather limited and the further extension of the peak reduction plan will be in all probability rather restricted.

T. E. Tynes: In regard to Mr. Woodbridge's question as to the amount of steam available, I would say that we usually have quite a little exhaust steam available for this purpose, so that our steam costs us practically nothing. At certain times, however, we find that our exhaust steam is not sufficient for heavy peaks and we have to take a little live steam to help out. We have a chart which records the amount of high-pressure steam taken, and from that we can calculate and charge to the turbine unit what the high-pressure steam has cost. Deducting that amount, we found that the turbine unit paid for itself in about two years and a half.

As to Mr. Bibbins's question in regard to charging on the one-hour peak, I am not prepared to answer that. I would like to study it a little more. Another reason why it is advantageous to us to keep down our peak is that we are allowed a certain limit above what is called our firm power; any amount in excess of that is added to our firm power, and we have to pay for that until the next period of readjustment.

DISCUSSION ON "PRESENT STATUS OF PRIME MOVERS" (STOTT, PIGOTT AND GORSUCH), DETROIT, MICH., JUNE 25, 1914. (SEE PROCEEDINGS FOR JUNE, 1914.)

(Subject to final revision for the Transactions).

R. Tschentscher: The division entitled "Gas Engines" comprises internal combustion prime movers using natural gas, producer gas, or blast furnace and coke oven gas. The relative measure in which each enters into the problem is not given.

In 1907, blast furnace gas engine installations began in the iron and steel industry. It was my lot at that time to place in service and operate the first plant of any considerable size. Power from the plant referred to was imperative, and there was therefore but little time for miscellaneous experiments, alterations, readjustments, etc. The conditions presented each day were varied. Experienced men were not obtainable, the hours were long, gas headaches were frequent, and the force was ever changing. The blast furnace operating conditions required readjustment from a condition of making pig iron with gas as a by-product used for air heating or steam generation purposes, to a condition where the maintenance of an adequate gas supply was necessary in order to supply electric power for the equipment used in making the pig iron. This proposition presented an entirely different phase to the blast furnace man. If he did not make the gas, the electric power could not be supplied, and hence he could make neither pig iron nor gas. I am afraid, therefore, that in some quarters a knowledge of the earlier more or less unsatisfactory power costs and operating results incident thereto, is still the basis for an opinion as to the status of the blast furnace gas engine in power stations at the present time.

The situation, however, based on the facts has been materially altered. It is true that from 1907 to 1909 the steel industry may have put into operation too many blast furnace gas engine plants, and that the gas engine reputation suffered thereby; but it is now recognized that after the experimental bill has been paid, gas engines operating on blast furnace gas have a footing based on true economics, namely, the return on the dollar invested, all factors considered.

At the present time statistics which I endeavored to collect show that there is approximately 450,000 kw. generating capacity in the steel plants that sent returns to me. Of that capacity, approximately 175,000 kw. use gas engine generation. The United States Steel Corporation alone has installed and in service approximately 140,000 kw. of gas engines operating from blast furnace gas. The various sizes of the plants range from 1000 kw. to 64,000 kw. in one plant.

About a year ago a paper was read before the Iron and Steel Institute, in which were given blast furnace gas electric power station costs, not including investment costs or other fixed charges, that were, approximately, $2.75 per 1000 kw-hr., being 2.7 mills per kw-hr. These figures were the results of a year's operation, 1912, I believe. These figures covered the operation of units, most of which were of the earlier type. Since that time the situation has materially changed. A 2000 kw. unit is not the limit of size by any means. Manufacturers are prepared to build now, and have had in operation for some time, units of 3000 kw. The exact weights I do not recall, but the weight per kilowatt for the 3000-kw. unit is much lower than it is for the 2000-kw. size. The operating costs for a plant composed of 3000 kw. units, as now manufactured and as operated for at least two and a half years, are lower than 2.7 mills.

J. R. Bibbins: Does that include the investment?

R. Tschentscher: No, the figures do not include investment. They are what is customarily considered as power station cost.

I wish to comment on a few specific points mentioned in the paper. In Fig. 16 are given fuel costs for a 750-kw. unit. For fear these may be taken as representative of what the gas engine can do, I will say that from my knowledge of the subject it appears to me to be not equitable to compare the 750-kw. unit with the turbine or reciprocating engine of that capacity. I am discussing this subject merely from the standpoint of blast furnace gas engines, not natural gas or producer gas engines. A steel plant requiring but 750 kw. would far better install a steam power prime mover or buy its power from some other source, because such a plant will probably have considerable periods in which there will be no gas available and no furnace in operation, and hence no power can be generated from the gas engine installation. I think it may be stated as a fact that the 750-kw. gas engine has no place in the steel plant. Therefore, comparison by using such units, as far as the blast furnace gas engine is concerned, may be misleading.

On the page following Fig. 16, the cost of $3 per ton is used as the cost for fuel in the relative comparisons, which, I believe, is too high when considering cost of fuel as used by steel plants. Most steel plants are located at a point of low fuel cost, and $2 would more nearly represent the true condition.

In the last paragraph of that page it is stated that the steam turbine has an overload capacity of approximately 25 per cent for 24 hours, while the gas engine is credited with an overload capacity for short periods, two hours or even less. That may apply very well to the motive power and of the unit. A steam turbine, no doubt, can operate for 24 hours a day at 25 per cent overload. To a large extent the gas engine may or may not be able to do that, depending on the design, depending on how free the manufacturer was in his guarantee. However, as far as the generator is concerned, I cannot see why the generator on the gas engine cannot have the same overload capacity for the same length of time as that of the turbine or the steam engine, provided they are built on the same standards.

Fig. 17 refers to some interesting data, namely, the cost of 20,000-kw. steam turbine units. I presume that what was intended here was a comparison of the motive power end, the prime mover end, of a plant having 20,000-kw. capacity. If that is the case, it does not appear to me to be fair to allow one 20,000-kw. turbine as the capacity of a 20,000-kw. station. No one, of course, would so design it. It would be designed with two 20,000-kw., or three 10,000-kw., or four 7500-kw., or perhaps two 15,000-kw. units, depending on the overload capacity, in case one unit is shut down. The reason I mention that is this—the 20,000-kw. turbine is compared with ten 2000-kw. gas engines. Ten 2000-kw. gas engines such as may now be purchased, I believe will have a greater yearly kilowatt output than one 20,000-kw. turbine unit. Therefore, it appears to me that a much fairer comparison would be to arrange the curves to refer to a 20,000-kw. output station, each prime mover being of the most suitable size. This might, in the case of the gas engine plant, consist safely of eight 3000-kw. blast furnace gas engines or perhaps seven. I will not attempt to say how many oil engines, as I am not familiar with the subject. On this basis the situation is altered, and these curves will assume an entirely different shape. Eight 3000-kw. gas engines may be purchased for materially less than $65 per kw., installed on the foundations. Not having the figures definitely at hand, I am, however, of the opinion that $50 or less will purchase the equipment.

The table at the bottom of page 983 deals with the total investment cost of gas engines and other prime movers, and I see it is stated that the cost of the producer gas engine is $140 per kw. Unless the price of producers has materially increased, I believe that is a high figure. When I first made my comments or notes here in connection with this particular table, I did not see that "producer gas" was put in parentheses. Some have the opinion that the blast furnace gas engine installation will run in the neighborhood of $140. It can be installed for materially less than that, not including, of course, land values, which vary so greatly, depending on location. Without considering land values I believe a 30,000-kw. plant may be installed for from $85 to $100 per kw., including the gas cleaning plant, together with the necessary piping, all auxiliaries, etc.

On page 985 the question of reliability is mentioned, giving the steam turbine by far the best of the argument. In that connection I wish again to say that the situation is materially different from what it was several years ago. The history of the operation of one particular plant for the past few years shows very reliable blast furnace gas engine operation—probably as reliable as a steam turbine plant, with the exception of, perhaps, a little unreliability in this local plant in the gas end supply end, due to periodically restricted furnace operations. As far as the power station operation is concerned, modern gas engines are practically as reliable as steam turbines. It must be remembered that blast furnace gas engines operate twenty-four hours a day, because the mills operate on a twenty-four hours per day basis.

A paragraph on the last page of the paper deals with the question of space economy. It is stated that a gas engine installation requires twenty times the space of a horizontal steam turbine installation. When that figure was presented to me I pictured an 8000-kw. plant with which I am familiar and tried to figure whether I could replace that with a 160,000-kw. horizontal turbine outfit. I am perfectly safe in saying I could not. I could probably put a 70,000-or 80,000-kw. horizontal steam turbine plant in that space.

I would like to call the attention of any one who is interested in the subject of producer gas engines to the installation which the Ford Motor Company is now in process of making. There will be three 3750-kw. generators, direct-connected to twin tandem combined gas-steam engines, a very unique installation. What they will realize I do not know—one side of the outfit being steam-driven and the other producer-gas-driven; the boilers to be mounted above the producers, and the feed water to be heated from the waste gas of the gas engines. I understood in conversation this morning with one of the representatives of the company, that they have overcome the usual difficulties, and on that basis we are likely to see some exceedingly economical results obtained at that plant.

In conclusion, I would like to say that the paper which has been presented to us this afternoon is of very great value, but one is apt to draw erroneous conclusions from a paper which treats of prime movers only, and it ought to be emphasized that all these figures should be taken as representing prime movers only, and not as being typical of the entire generating plant. Operating conditions and costs of the boiler plant, the producer plant, or the gas cleaning plant, or similar factors relative to auxiliaries, may greatly modify the conclusions which may be drawn from a consideration of prime movers only

J. R. Bibbins: This admirable paper brings forcibly to mind two fundamental facts both intimately related to the cost of power production: (a) the tremendously rapid increase in the capacity and the cost and weight efficiency of steam turbine units; (b) the correspondingly rapid aging of power generating apparatus by change in the art, and the heavy replacement or obsolescence charges resulting therefrom.

The one is evident on the face of the facts presented, the other, by experience only, and yet in an established property the burden of fixed charges due to obsolescence must be reckoned with and might operate to modify largely the relative economic positions of the various prime movers represented in this paper. It is to be hoped that the authors will present something further on this aspect of the question in the future.

While the general economic principles employed in this paper are quite unimpeachable, it seems to me that forced comparisons between the relatively small units of the internal combustion type and the large units of the steam turbine type can hardly lead to conclusions fundamentally sound in the broader aspect of *system* vs. *size*. Thus the comparison drawn here for a 20,000-kw. plant is justifiable only in so far as it applies to the forced conditions of ten gas units vs. one steam unit. Obviously neither installation would receive serious consideration to-day as an effective layout, and a true comparison of systems should be made on smaller capacities. Thus in Fig. 18, the heat consumption curve of a 2000-kw. turbine would appear to much less advantage than that of the 20,000-kw. unit.

Further, the authors state, on the next page, "An important feature of the steam turbine, and especially the oil engine, is that the efficiency does not materially decrease until the load falls below 25 per cent of the normal rating, whereas the gas engine changes rapidly." From the heat consumption curves, Fig. 18, unless I interpret them incorrectly, the gas engine seems to hold its economy on light loads, comparatively speaking, better than either the oil engine or the turbine, due apparently to the better inherent efficiency of the Otto gas cycle over the Rankine steam cycle.

It is well that the authors have brought out the importance (page 962) of the Rankine cycle as a detector of spurious water rates or heat consumption curves. I have in mind the case of a heat engine economy curve published some years ago as a wonderful performance. It looked rather "fishy," and I did not take even the trouble to work out the thermal efficiency, but simply applied the Willans law, as in Fig. 1. This very simple graphical method plainly showed that the heat consumption curve published was in error.

I am interested to know whether the net basis of heat units has been used in making these comparisons. Of course, either net or gross would not affect the *over-all* efficiency of a plant, at the coal pile, but it would most decidedly in the comparison of these thermal efficiencies. Also, approximately uniform gas engine piston speed was presumably used in making these comparisons of engines of various sizes. In the matter of the oil engine, while some of the auxiliaries might be dispensed with, I do not quite see how the air compressor can be disregarded. It is rather difficult to conceive of a Diesel type of engine without any auxiliaries, because the engine is absolutely dependent upon the air injection for its operation.

In Figs. 16 and 17 the authors have presented an argument that seems rather hard to combat, with two exceptions. One is the unfortunate choice in the size of units. Thus, in this comparison between the 20,000-kw. steam unit and the ten 2000-kw. gas units, it is important that these costs and economy curves should be correlated not only as to size, but as to method of operation. It should be assumed that the smaller units were put into operation consecutively. That is, 50 per cent plant rating should refer to *half load* on the 20,000-kw. machine, and half of the number of smaller machines running at *full load*, rather than half load on all of the small machines. I must confess that the latter method, here used, seems unduly unfavorable to the smaller units, because it is obviously possible, in an underloaded plant, to build up prime mover capacity to meet the load with far better over-all efficiency in small units than with one very large unit.

The other point is in regard to the price of steam or gas coal, $3 per ton. It was my pleasure to have quite intimate knowledge of the development of the bituminous producer in the use of low-grade fuels of various kinds. I have not followed very recent developments, but in view of the success attained at that time it seems to me inequitable, except in certain individual locations, to assign to the producer gas plant as high a price for fuel as for steam coal. If the producer has any special field, it is as an apparatus designed for, and capable of, using low-grade fuels—for instance, the lignites in the West. Thus, any possibility of difference in the cost of coal (Fig. 16), would operate to overcome the higher investment cost assigned to the power gas plant.

Finally, there is one thought which occurred to me in this connection, especially as to the theory of prime movers, and their application, presumably, to central station work. In a previous paper, presented two days ago at this meeting, the question of special peak load apparatus came under discussion, and there occurred to me at that time, as many times before, the question whether the complete standardization of prime movers is absolutely essential in a plant only half of which may be called upon for peak load duty, and not for an hour necessarily, but perhaps for only ten or fifteen minutes. In street railway practise, for example, the maximum passenger movement occurs usually within ten minutes after 5:30 p.m. The reflex of this great volume of passenger movement on the power plant load does not by any means last over the hour.

Now, on the other hand, generators are universally rated upon at least an hour basis, and the question therefore arises, whether it would not be possible to develop a type of prime movers or combination of prime movers, of minimum cost, perhaps not quite as efficient (because the last grain of efficiency would not be necessary at the extreme peak), but of a type exceedingly sturdy in construction, one that could stand higher temperatures and excessive overloads for these short peak load periods. Of course, the steam turbine is able to do this now, though not designed *primarily* for peak load conditions. Perhaps a special combination of short peak ratings would suffice. It would be interesting to know how near power plant apparatus, as it is designed today, approaches the limit of ultimate capacity of materials used. It certainly is not impossible to determine this in the case of the gas engine installation, which, as you can see, is very seriously handicapped on the peak load basis.

H. M. Hobart: The authors give a table at the bottom of page 983 in which the total investment cost per kilowatt is given. With the greatly decreased cost of steam turbines, the cost of the prime movers and the generators is now perhaps one-half, or even less, of the outlay for land and buildings in the case of a station located in or near a large city. It would be interesting if, in the first column of this table, the authors would indicate more precisely whether the total investment cost per kilowatt, at any rate in the case of steam turbine plants, includes a station to be laid down in or near a large city.

Incidentally it may be pointed out that the $65, in the first column, in the case of the steam turbine plant, does not agree with the percentage of total investment in the last column, namely, 15 per cent, together with the figure of $7.50 for the cost of prime mover and generator per kilowatt, in the case of the 20,000-kw. set. Either the figure in the first column should be $50 per kw. for the total investment, to agree with the $7.50 in the center column, or else, if in the first column the total investment cost per kilowatt should be $65, the percentage of total investment, given in the last column, should be 11.5.

But I do not wish to lay special stress on these little errors. I would have gladly pointed them out personally to the authors —but I want to attract attention to this point of total investment cost. I believe in the reply by the authors they will tell us that the figure in the first column should be $50, and that the figure in the last column is correct as it stands. I should also be glad if they would qualify that $50, with a precise statement of the allowance they have made for the land and buildings in the case they have in mind, since that is probably the largest component of all, and leaves us in a very vague frame of mind as to the composition of the total investment. Figures should preferably be given for each particular component of the total investment, and I should like to ask the authors to supply these component costs. It would be much appreciated if the authors would make a precise statement of the total cost in and near large cities, and also the corresponding allowance for land and buildings. This could be followed by the corresponding figures for the same size and design of station, but located exclusively with reference to an economical supply of coal and water and low prices for land. The addition of these data would be much appreciated.

E. D. Dreyfus: The admitted breadth of the subject of prime movers makes it possible only to treat of all of its phases but partially in a limited paper; however, sufficient has been presented to demonstrate that the steam turbine holds a superior position in view of the present prices of the different types of equipment and the existing fuel costs. Such an attitude regarding the equipment situation has been quite pronounced in the power industry during the past two or three years. As pointed out in the paper, the steam engine has for some time been rapidly losing ground. Greater use of the gas engine has been seriously checked by the lagging progress of the producer. While natural gas is an ideal fuel for the internal combustion engine, the available supply for power purposes is limited and therefore its price is too uncertain. Very little practical headway has been made in the utilization of the inferior grades of fuel such as peat, lignite and the low-grade coals.

While the gas engine has taken a prominent position in blast furnace and steel mill work, I do not believe it can fairly claim an undisputed title to that field. Possibly for a limited capacity it may show a small economic advantage. However, when the plant becomes of an important size the advantage in fuel economy not only vanishes, as illustrated in the paper, but the gas engine is exceedingly handicapped by its greater maintenance and attendance costs. For such reasons the gas engine will be unable to maintain its former popularity even among the steel men.

The writer made the statement about three years ago that the demand for gas engine plants would only be for installations of 1000 kw. or less, until there should be a material rise in the price of coal. Expected further developments in gas power equipment have also, no doubt, deterred the power plant owner from installing this type of equipment.

It might be well to illustrate by example the bearing the item of labor has upon the total operating cost. The labor cost in a gas producer plant containing three 300-kw. units would be about $830 per month, while for a similar size steam turbine station it would be in the neighborhood of $570. For such small size plants the difference may not be serious, but on the other hand, if we were to compare plants say of three units of 2000 kw. each, the gas engine station would involve a labor cost of about $3425, while the same capacity steam station would demand only $2020, roughly. If we take a plant of 20,000 kw., consisting, in the case of gas engines, of ten 2000-kw. units, and if steam turbines are used, of about four 5000-kw. units, the respective labor costs would be in the neigborhood of $11,180 and $4,475 per month. As the fuel economy of the gas engine is but little better than the steam station when such sizes are considered, and, moreover, as the labor cost in the gas engine plant exceeds one-third the total operating expense, the internal combustion engine is obviously given a decided setback. This contrast has been made upon the basis of a 50 per cent load factor. The lower the load factor, the less economically will the operating force be applied, as a general proposition, so that labor cost will in a somewhat greater degree prejudice the gas engine plant at low load factors. It is rather difficult to show all the combination of factors at work to influence operating cost under the wide range of conditions that obtain.

I attempted to show, in a paper presented before the Association of Iron and Steel Electrical Engineers in 1911, the general relations of the different prime movers by taking into account all the elemental factors. As germane to the discussion, I am presenting (Fig. 1) one of the figures prepared at that time, which shows results obtained by taking into account all the different costs that enter into the power problem. Excepting the bottom curve, all the comparisons are between gas engine plants and steam turbine plants. The area above the curves favors the gas engine and conversely that below represents the economical field of the steam turbine. It will be observed that for large gas producer stations operating on low load factors, the cost of coal would have to be at some fabulous price to justify their existence. In the hydroelectric plant it is not only the absence of fuel that makes for low costs (assuming reasonable development cost), but the small operating and

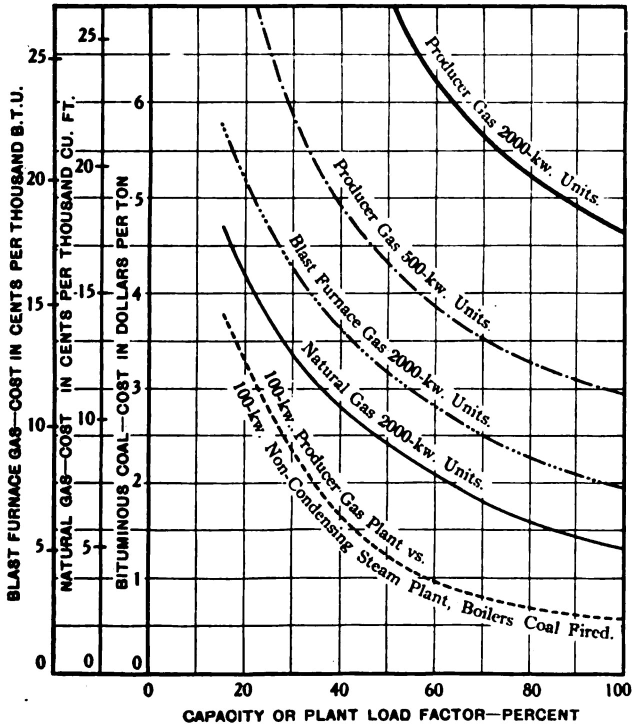

FIG. 1—PROPORTIONATE EQUALITY CURVES

Showing balance of total costs of generation in gas and steam plants with variable fuel prices and load factors.

Area above curves favors the gas engine; below, the steam turbine plants prove more economical. Based on general conditions in the text.

Fuel values:

Bituminous coal	13,000 B.t.u.
Natural gas	975 B.t.u.
Blast furnace gas	80 B.t.u.

maintenance expense gives such a plant an excellent position when within close range of a favorable power market.

Referring to costs of oil engines, some recent figures obtained from a large American manufacturer indicated that the complete oil engine plant could be installed (including buildings and foundations) at costs ranging from $150 down to $100, depending upon the size of the plant. A representative of a foreign oil engine builder claimed that oil engines could be delivered and erected within reasonable shipping distance from port of entry, complete with building, at costs about 20 per cent below the figures just given. This is expecting a little too much, but the oil engine builders are working towards a reduction in the cost of the equipment, which should of course give this type of equipment a better competitive position. On the other hand, the lack of stability of oil prices has a disquieting effect upon the use of the oil engine. In the South and Southwest in the vicinity of the oil fields or in the neighborhood of the ports receiving Mexican crude, the oil engine increases in importance.

In any consideration of prime movers it is becoming better understood right along that we can not allow ourselves to be guided by technical conditions only. The human element enters seriously into a question of this kind. For a given equipment the results obtained under actual operating conditions may differ in a marked degree, depending upon the ability and conscientiousness of the chief and his crew. This is more apparent in steam plants, as, with their liberal overload capacity, the output may be maintained though the efficiency may have fallen off greatly. With the producer gas engine plant, in the first place, a more competent force is required, and then if the force should become negligent the quality of the gas will suffer and at the same time no doubt there will result an inefficient mixture, so that the engine may fail to pull the load. Therefore, it may be said the gas engine will depart the least from its best operating efficiency. Another point—if the external load on the station is of a widely fluctuating character, the unit or "machine" load factor will be unfavorable, on account of the inadvisibility of operating without a conservative margin. In fact, if a gas engine is overloaded to any extent it is liable to fall out of step, and if the station comprises gas engines only, the effect becomes progressive and the whole plant will go down. I have observed complete shut-downs from just such causes. There are a great many operating considerations to be borne in mind, and this is unquestionably accountable for the marked inactivity of the gas engine business in the past few years.

H. G. Stott: Mr. Tschentscher is entirely mistaken in assuming that these comparisons refer to blast furnace gas practise, as that is specifically exempted. The blast furnace gas plant is not considered in the paper, excepting the reference on the page where we begin discussion of the gas engine, that is, on page 962, where you will find due credit is given to the position of the large gas engines in steel plants, where we say, " The development of large gas engines is largely due to the ideal conditions existing in steel industries, where large quantities of blast furnace gas are available, requiring only cleaning to make a perfect fuel for this type of prime mover." Then we go on and refer to the fact that they have reached a capacity of 6000 brake h.p. for a single unit of the twin tandem type.

Now, some question was raised by Mr. Tschentscher and also by Mr. Bibbins, as to the comparison of costs of producing power, based upon the assumption of equal cost of fuel. I admit that possibly may be a little unfair, but how are you going to do it in any other way, in making comparisons? If we use cheaper fuel for the gas engine than we do for the steam turbine, there would be a complaint from the other side, because, as you know, in a great many cases, anthracite is used in producer gas engines, and anthracite is usually—not always—but in the larger sizes, is much more expensive than bituminous or semibituminous, so I think it is clear that for the purpose of comparison it was an impossibility for us to do anything but use the same price of fuel in both cases, because any needed correction can be made in this comparison. If, for example, you find the fuel to be used in the producer is 10 per cent or 50 per cent cheaper, it is quite easy to make this correction in these curves. If we had started on an unequal assumption of price, it would have been very difficult to make the correction.

Mr. Bibbins asked about the kind of heat unit, whether gross or net heat unit. I do not understand the question, but I would say that we used the mean B. t. u., which is the average B.t.u. contained in steam between a temperature of 32 deg. and 212 deg., which is given in practically all the modern steam tables, which is 1/180 of the heat contained between two points, between 32 deg. and 212 deg.

There were a number of other questions raised, which I will be glad to answer further by a written discussion, as our time is limited now.

Of course, in making these comparisons it is obvious you must make generalizations. We have compared in one table here the results of all units; for example, in Fig. 16 we go up to a maximum size of 750-kw. units, but, in order to be perfectly fair to the larger prime mover, namely, the steam turbine, it is obvious we had to consider 20,000-kw. turbines. We might have gone to the 30,000-kw. turbine, as that is now an ordinary type and design; however, we only went to the 20,000-kw. turbine, as there are a number of those in actual operation today. There was no way, which we could see, to compare the operation of the 20,000-kw. unit, as a unit, other than to take a number of multiples of the smaller ones to compare with it. So far as we know, the largest gas engines in actual operation, outside of the steel industry, are those of 2000 kw. rating, and therefore we chose that size, and the same reasoning applies to the oil engine. If we multiply that by two in one case and by fifty in another case, it does not alter the relative value, and simply quoting the three machines, so as to make them comparable, is not fair to the steam turbine, unless we show what can be done with the larger sizes. That is the reason we did it.

The paper is also criticised as not covering the entire cost of the power plant. This paper is one on prime movers, and not on power plant. It seemed to us that we had to take into consideration the fuel consumption, but that we could cut out all auxiliaries. The consumption of power by the auxiliaries of the various types of prime movers is not greatly different in relative cases. The total percentage of power is from 6 to 8 per cent in nearly all cases, so that we had to make certain assumptions in order to make these comparisons on what seemed fairly equal terms.

S. Barfoed (by letter): This paper is a résumé for conditions in that section of the country where coal is obtainable at reasonable prices. In large sections of the West, however, oil is the common fuel, and the curves given under " Finance and Economics" must be revised for this condition. Assume the oil to have 18,000 B.t.u. per pound, then with oil-fired boilers at full load a kilowatt-hour can be had from 1.26 lb. of oil, corresponding to about 259 kw-hr. per barrel of oil. With oil at 4 cents per gallon the fuel cost at full load and with oil-fired boilers will be 6.5 mills.

In Fig. 2 there have been reproduced the curves of Fig. 16 in the paper and a curve has been added for a turbine with oil-fired boilers. Combining this curve with the curve for investment costs, and also the curve for the oil engine with oil at 4 cents a gallon, with the corresponding investment cost curve, it is seen that the oil engine has a considerable margin over the turbine from full load to half load. With increasing oil prices the margin would be still greater.

Franklin M. Farwell (by letter): It seems to me that the authors, without so stating, are thinking largely in terms of great capacity power stations. Almost all well-informed engineers will concede that for power stations large enough to admit of the use of units of 20,000-kw. capacity the steam turbine has no competitor, with the possible exception of water power, but when it comes to the matter of small stations it is a different story, and I believe that many engineers will question the authors' conclusions when applied to power stations of a size where all forms of prime movers are on a comparable basis.

The paper dismisses with a few brief words the reciprocating engine as if it were something not worth considering. No mention was made of a form of generating plant popularly known as the "locomobile." Many prime movers of this type are in use in various parts of the world and at least two concerns are selling them in this country now. These engines are especially adapted for driving generators of 600 kw. or under and many tests have demonstrated that the thermodynamic efficiency closely approximates that of the gas engine, and there are many who will question the ability of the present steam turbine to equal, much less exceed, these efficiencies, except in view of the possibilities offered by the mercury boiler and turbine as brought out by Mr. W. L. R. Emmet (See PROCEEDINGS of

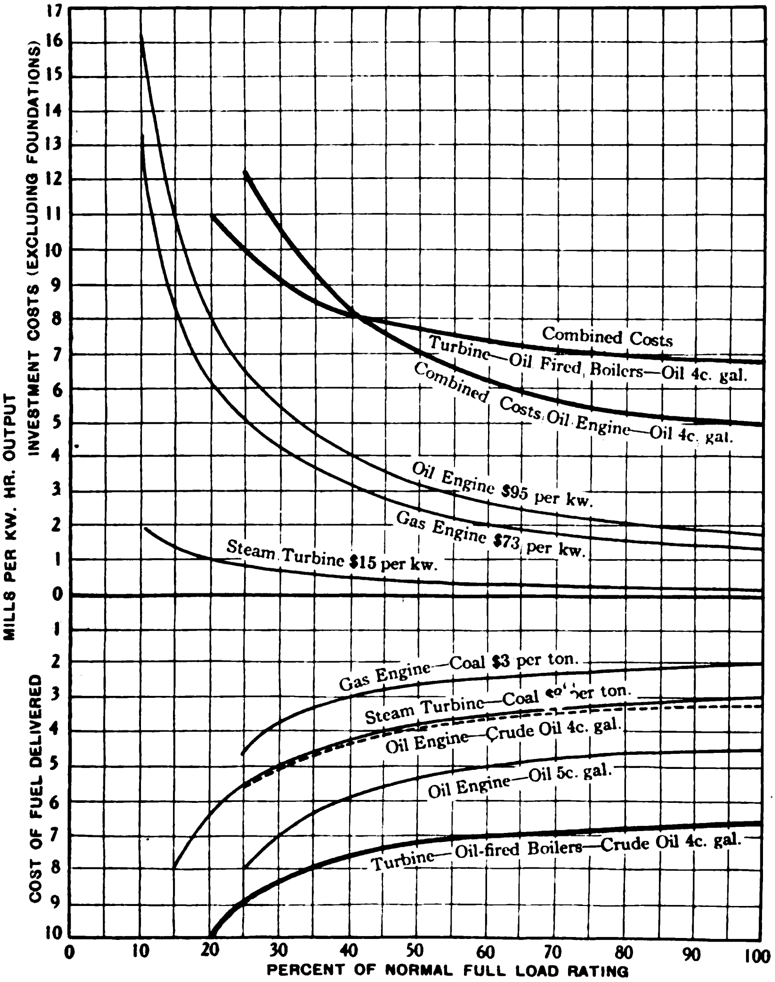

FIG. 2—RELATIVE INVESTMENT AND FUEL COSTS

Of 750-kw. steam turbine (one curve for coal firing, one for oil firing), gas engine, and oil engine, including direct-connected 60-cycle generator operating at different percentages of normal full load.

A. I. E. E. for March, 1914). These entire units, auxiliaries included, will cost about the same as a gas engine of the same rating, and very high efficiencies are covered by the manufacturers' guarantee.

In Fig. 16 in the paper, the authors attempt to make a comparison of the various prime movers on the basis of units of 750-kw. capacity. As the curves in Fig. 16 stand, the investment cost for the oil engine is eight times that of the steam turbine and that of the gas engine approximately six times that of the steam turbine. A little further on in the paper is a table giving the total investment cost per kilowatt of stations using various forms of prime movers. According to this table the cost of an oil engine station is less than twice the cost of a steam turbine station, while the cost of a gas engine station is only slightly over twice the cost of a steam turbine station. There is a very evident discrepancy here. This discrepancy is doubtless due to the fact that in Fig. 16 the investment cost in the case of the oil engine covers practically a complete generating unit, but in the other cases only part of the complete generating unit is considered, as the producer in the case of the gas engine and the boiler in the case of the turbine are left out of consideration. It seems to me that this is a decidedly unfair comparison; that the producer in the case of the gas engine and the boiler in the case of the steam turbine are the primary generators of power and cannot consistently be left out in comparison with oil engines.

As the high economy of fuel in a steam turbine is largely dependent upon a good vacuum and high superheat, in other words, is to a considerable degree dependent upon expensive auxiliary equipment, it would seem no more than fair to include the auxiliaries. Much has been claimed for the small space required for the steam turbine, but in most such comparisons no account is taken of the boiler plant. If the boiler plant is considered when comparing the space economy of the steam turbine with oil engines for small power stations, the steam turbine does not appear to have much advantage. In view of this it seems to me that total station cost is the only fair basis for investment cost comparison.

The table of total investment cost per kilowatt included in the paper gives values for a large capacity station, but if we add to them the engine cost differences between Figs. 16 and 17, viz., $10 for oil engines, $8 for gas engines and $7.50 for the steam turbine, we have $148 for the gas engine, $130 for the oil engine and $72.50 for the steam turbine, which would seem to be reasonable for a station using 750-kw. units. On the basis of these figures I submit, in Fig. 3 herewith, a revision of the curves in Fig. 16. Concerning the lower part of the figures, showing the fuel costs, I desire to state that it seemed to me that the values given for the steam turbines are rather lower than are commonly found for working conditions, so in the accompanying curves I have boosted up the values to what seem to me to be more reasonably attainable figures with turbines of such small size. Concerning the oil engine, I find that there are several authentic cases where the total operating cost, exclusive of attendance, is considerably below that given in Fig. 16 for fuel alone, and that there are regions where crude oil can be purchased for as low as 2.5 cents per gal. In the curve submitted I have used 3 cents per gal. I believe that some of the manufacturers of oil engines are willing to guarantee a higher thermal efficiency than that given in the paper, but I neglected that in the curves. The fuel costs for the gas engine I did not find any reason for changing. It seems to me that the

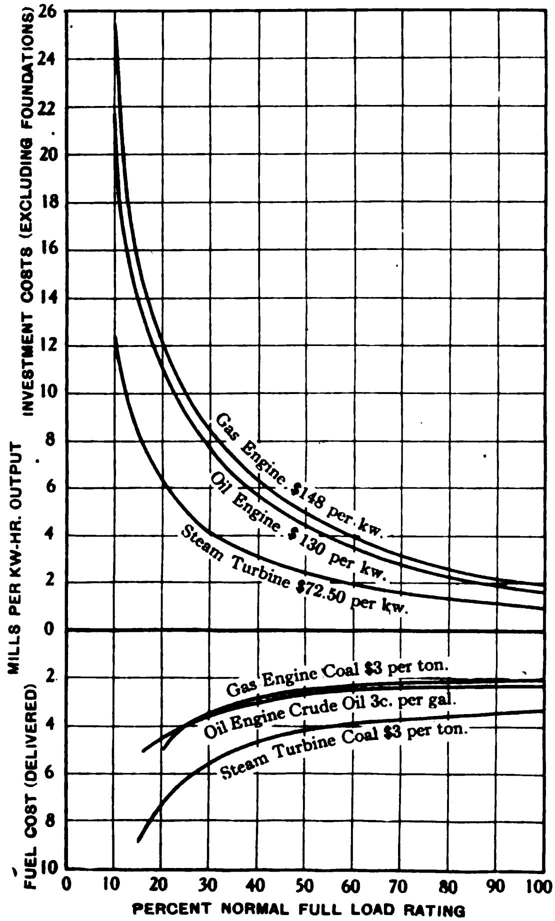

Fig. 3

curves in Fig. 3, at least insofar as they concern the investment cost, are a much fairer basis for the comparison of prime movers for small plants than the curves submitted by the authors of the paper.

By adding the ordinates for investment cost and fuel cost in the curves I have given, it is apparent that there is very little difference among the three forms of prime movers. If we consider even smaller stations, say those with units of about half the size of those considered in the curve, the oil engine and the gas engine will have a decided advantage over the steam turbine. It is worth while to note in the case of the gas engine and oil engine that jacket water and water heated by exhaust heat economizers can be used for heating and for industrial processes where hot water is needed, thus extracting still more heat from the fuel without in any way affecting the engine efficiency.

I do not think that any one type of prime mover can be made to meet all cases. I believe in selecting the one best adapted to the local requirements.

While there are many central stations of enormous capacity, still a very large percentage of power generated, particularly in industrial plants, is produced in stations using units of 750 kw. or less, so it seems to me that the paper under discussion, considering the scope it is intended to have, hardly gives the status of prime movers for small stations with the fairness that ought to be expected.

W. S. Gorsuch (by letter): Curves shown in Figs. 16 and 17 have been criticised as being unfair to the oil and producer or natural gas engines. In Fig. 16 the largest oil engine for which reliable data could be obtained was taken as the basis, and a corresponding size gas engine and steam turbine selected for comparative purposes. In fact, the largest oil engine unit in successful operation in this country today is less than 500 h.p. capacity; therefore, in taking a unit of 750 h.p., the oil engine is being favored.

The object of Fig. 17 is to show the advantage that the steam turbine has in being made in large sizes, 20,000 kw. being taken, as many such units are in actual operation. To make the curves showing investment costs comparable, the cost per kilowatt normal rating was determined on the basis of purchasing 10 producer gas and 40 oil units of the largest sizes in actual operation today. The lower curves show the relative economy of the individual units and have no reference to plant operation.

Regarding Mr. Tschentscher's comments on "Space Economy," the figures given on the last page of the paper are the average minima and maxima of different sizes of machines in actual operation today, excluding the blast furnace gas engine.

If Mr. Farwell will refer to page 978, under the heading "Finance and Economics" he will find it specifically stated that the scope of this paper is limited to prime movers; consequently the upper curves in Figs. 16 and 17 show the investment costs in units per kilowatt-hour output at various percentages of full-load rating for prime movers only, that is, the cost of prime mover installed, exclusive of foundation. The figures given in the table on page 983 give investment costs of plants using various types of prime movers, and include all costs, with the exception of real estate.

The figures and curves submitted by Mr. Farwell are based on the assumption that the investment cost per kilowatt installed capacity of all the items contained in a small power plant, exclusive of the prime mover, will be the same as for a station of much larger capacity, which obviously is erroneous. The cost of fuel per kilowatt-hour output for the steam turbine, as given in Fig. 16, is based on the average efficiency obtained from this size machine.

The percentage of total investment for steam turbines in the last column of the table on page 983, namely 15 per cent, is an error, and should read 11.5 per cent, as pointed out by Mr. Hobart.

R. J. S. Pigott (by letter): Replying to Mr. Tschentscher, if he will refer to page 963, under the heading "Capacity," no doubt the question in his mind will be removed as to the relative overload capacities on gas engines and turbines. While his figures in criticism of our costs are somewhat indefinite as a basis of analysis, the figures presented in our paper were obtained from a number of manufacturers and from purchase prices in the hands of a number of buyers.

Referring to Mr. Bibbins's statement, "From the heat consumption curves, Fig. 18, unless I interpret them incorrectly, the gas engine seems to hold its own on light loads," on checking up the curves I find that the titles for the curves "Gas engine, all sizes," and "20,000-kw. steam turbine," have been accidentally interchanged. If these two titles are exchanged, the curves in Fig. 18 will agree with those in Fig. 19, and with Mr. Bibbins's statement.

Referring to the statement of Mr. Farwell concerning the locomobile: This type of prime mover has been installed in this country in less than half a dozen small plants, the first early in 1913. Few or no maintenance data are available, but it is certain that with the high superheats employed, the maintenance will not be less than with the ordinary reciprocating engine using superheat. The inflexibility of a type in which one boiler is definitely tied to one engine is a very pronounced objection. The very high "efficiencies" usually quoted, are water rates, which naturally, with the high superheat and re-heat employed, are low, but low water rate is not necessarily concomitant with high efficiency.

Referring to the Rankine cycle, the performance of locomobiles is little better than that of ordinary reciprocating engines. Table I, herewith, taken from tests of the first American locomobile, published in *Power* May 20, 1913, shows this. With similar superheat and re-heat the turbine would do equally well, and if worth while to do it, could readily be arranged in a similar manner to the locomobile.

TABLE I

Test	Brake h.p.	Lb. Steam b. h. p.-hr.	Pressure lb. gage.	Vacuum, in. of Hg.	Superheat	Therm. effc'y	Efficiency ratio
3	127	10.82	196.5	27.15	256.	18.7	62.5
4	148	11.08	206.5	26.62	273	18.3	60.7
5	115	10.9	201.5	28.58	227.6	18.2	55.9
6	154	11.45	198.5	27.27	273.5	17.5	57.7
7	192	10.25	204.	27.23	302	19.4	62.8
10	77	14.65	200.	27.75	170.4	14.2	46.5

DISCUSSION ON "THE SPHERE GAP AS A MEANS OF MEASURING HIGH VOLTAGE" (PEEK), "THE ELECTRIC STRENGTH OF AIR—V, THE INFLUENCE OF FREQUENCY" (WHITEHEAD AND GORTON), AND "SPHERE GAP DISCHARGE VOLTAGES AT HIGH FREQUENCIES" (CLARK AND RYAN), DETROIT, MICH., JUNE 24, 1914. (SEE PROCEEDINGS FOR JUNE, 1914.)

(*Subject to final revision for the Transactions.*)

L. W. Chubb: These three papers presented under the auspices of the Electrophysics Committee are very interesting, and they add a gread deal to our knowledge of high-voltage phenomena.

The paper on the sphere gap by Mr. Peek adds some valuable experimental data on the effect of barometric pressure on the gap voltages. The effect of temperature, however, as expressed in the empirical formula, seems to be a matter of assumption based on free-path and pressure, but not confirmed by experimental data. The inverse proportionality between breakdown voltage and absolute temperature may hold throughout the range of atmospheric temperatures, but the stream of negative electrons from hot metallic electrodes will possibly have a greater effect at high temperatures.

The theories of corona formation and breakdown voltage so far advanced can hardly be adopted as laws until they are more thoroughly tested out, between wider limits.

The formulas given by Mr. Peek agree well with his experimental results, as high as 320,000 volts. Our own direct calibration with the 25-cm. and 50-cm. spheres agree very well as high as 320,000 volts, with the 50-cm. spheres (one grounded), but above this point the formula and the calculated values given in Table IV do not check with experimental data. For instance, for the grounded case a value in Table IV gives for a separation of 50 cm. a breadkown voltage of 541,000 volts. Direct calibrations show 478,000 when the insulated sphere was freely suspended from a crane and 458,000 volts when both spheres are mounted in the standard frame proposed by Messrs. Farnsworth and Fortescue. The last value given for non-grounded spheres shows a separation of 75 cm. at 725,000 volts. Our direct calibrations show a separation of just twice this gap at the same voltage and without visible corona on the spheres. Below 320,000 volts the points can be reproduced easily, they check the values given in the paper and the sphere gap seems to be a reliable standard for measuring maximum voltage. Above 320,000 volts the gap is unsteady, the strength of the gap is apparently much lowered, extraneous bodies have a greater influence and barometric pressure seems to have a much greater effect than is indicated by the formula. Tests have been made, with one sphere grounded, to voltages over 600,000, and with both spheres insulated, to over 900,000 volts. In the tests there was an increasing discrepancy with voltage increase, between the curves given in the paper and direct calibrations.

At high voltages there is a time effect of breakdown voltage.

Thus at a gap setting of 10 cm. the voltage was quickly raised and the gap broke at 188,000 volts. The gap was then increased one per cent and the same voltage broke over after an application of 55 sec. A second test showed a lapse of 40 sec. The gap was again increased one per cent, and it required 160 sec. for the same voltage to cause a break down. Similar effects were shown at other voltages above and below 188,000. At 100,000 volts the effect is inappreciable and below 95,000 volts no time effect could be noticed.

The effect of light is also being investigated and seems to play an important part between terminals which break above the corona point, but, within the range of working voltages, light of ordinary wave lengths has very little effect on the calibration of the sphere gap.

It was thought that the presence of so much corona in the neighborhood of the sphere gap during high-voltage tests might lower the breakdown voltage between spheres. Tests were made blowing air upon the gap from the side opposite to the high-tension apparatus. This air was drawn in a large wooden flume about 20 cm. (65 ft.) from the gap and forced with a low-pressure blower across the gap. It was found that the air blast, instead of making the breakdown voltages higher and more consistent as expected, made the behavior more erratic, and caused premature static flash-overs across a gap of 25 or 50 per cent greater than the separation required for final breakdown. Several explanations have been put forth to cover this effect, but they need not be mentioned at this time.

The precautions against oscillation given by Mr. Peek are very important, and the damping resistance both in the primary circuit and in series with the gap is very necessary.

The paper by Messrs. Whitehead and Gorton is certainly an example of a good record of the work done. After reading such a paper, one feels that he has no questions to ask why, how or under what conditions the several steps were followed out.

The vibration of the wire at high frequencies seems to prove that the wire was well centered. A stroboscopic view of the vibrating wire would probably show the wire to be vibrating at its natural period with an increased corona on the side of the wire in the direction of the instantaneous deflection. This corona causes the familiar electric wind, the reaction of which tends to restore the wire to the center. A possible explanation is that due to the lag of corona formation upon the deflection of the wire there is a greater force acting on the wire when it is traveling toward the center than when it is traveling outward, which would cause a sustained vibration.

The three possible explanations for the effect of frequency on corona formation, given on the last two pages of the paper, seem to indicate that at high frequency the appearance of corona would be at an increased voltage, while the results show the reverse effect.

All the papers show discharge at a lower voltage at high frequency, and the authors are certainly to be congratulated on this agreement. The discussion over a year ago which probably stimulated the frequency tests, contains several statements that the gap would be stronger at high frequency. The new records show clearly that direct tests rather than theories should be used to study such complex phenomena.

F. C. Caldwell: Would there be any chance for error due to the drop in the high series resistance, especially at high frequencies, or would the fact that the charging current is out of phase eliminate any such error?

D. M. Mahood: Referring to curves of Fig. 5, in the paper by Messrs. Clark and Ryan, showing discharge voltage for high frequency as almost uniformly 4.5 kilovolts below the 25-cycle voltages, it is suggested that this is due to the fact that pure undamped waves were not obtained during these observations. With about 10 to 15 ohms high-frequency resistance for the inductances L_1 and L_2 in the oscillating circuit, about 8 ohms high-frequency resistance for the carborundum safety resistance rods in series with the sphere gap, and about 2 ohms operating resistance of the arc itself, there exists a decrement of apparently 0.02. The cyclograph used, indicating only the r.m.s. value of potential existing, permits the periodic high swinging potential which breaks down the gap to slip by without being taken into consideration during observations.

The conditions existing during tests indicated in the first paragraph of the second page of the paper, showing 17.6 amperes direct current about equal to alternating current (12.5 r.m.s. or 17.6 maximum value) in the arc, are extremely unstable. Our experience with Poulsen arcs has shown that where such conditions exist there is considerable fluctuation of voltage and other conditions of the arc. With this maximum voltage value jumping up at times and not possible of indication on any of the instruments used, the discrepancy between the 25-cycle and high-frequency curves may result.

The best oscillating arcs constructed and specially designed for stability for measuring purposes (those of Lindemann, duplicating those of the German Reichsanstalt,) gave 2 per cent variation in amplitude at 133,000 cycles. Methods for standardized calibration making use of the oscillating arc are capable of too much error, caused by the instability combined with the occasionally swinging high-amplitude wave, and should not be considered conclusive until an opportunity is afforded to check the high-frequency results under more stable conditions, using high-frequency generator with absolutely constant speed maintained.

Charles Fortescue: Discussing first Mr. Peek's paper, the results of the tests under various atmospheric conditions, pressure, frequency, etc., are a valuable addition to our knowledge of the subject. It is gratifying to find that these tests agree with theoretical figures, as far as they have been carried out. Mr. Peek's tables of spark-over voltages add nothing to the data already available on the subject, except in confirmation of the results obtained for 25-cm. spheres, with smaller spheres. On the contrary, Mr. Peek's assumption of constant apparent potential gradient at spark-over, for a given sphere, based on his assumption that this quantity is the same function of $\frac{x}{r}$ as the true intensity, leads to no useful result, and in my opinion beclouds the real issue. We are confronted with two problems: first, the calibration of sphere spark gaps of various sizes; second, determination of the theory of the voltage breakdown of the spark gap.

The old theory propounded by Russell has been found not satisfactory. Mr. Peek has evolved a theory of the effect of shanks. I do not think that the discrepancy can be attributed to the shanks. The shanks have very little effect on the breakdown voltage. I think it must be due to some other cause, and in attributing it to the effects of shanks, we are losing sight of the real issue and preventing ourselves from finding out the real reason of the discrepancy.

We have been working on the calibration of the spark gap in Pittsburgh, and as Mr. Chubb states, we have carried calibrations on a grounded 50-cm. spark gap from potentials of 300,000 volts up to 600,000 and above. In making measurements of the maximum value, we use the condenser terminal as a condenser. The condenser terminal is an excellent condenser. We judge from our experiments that, the effect of the external bodies on the capacity can be made extremely small.

In our measurements there was no corona present on the terminal itself, under any of the measurements, except on the small choke coil on the top of the terminal. The wire leading to the spark gap had considerable corona, a soft glow without streamers. There was a certain amount of corona on the resistance leading to the spark gap and on the bushing through which the shank of the spark gap passed. It may be that in making our measurements by means of this condenser, and averaging the value of the charging current with the condenser method, there are oscillations set up due to corona disturbances, which, of course, take place at the peak of the wave, which may not be taken into account in the average value of the charging current of the condenser, so that it is possible that the effect of the corona in the wires, etc., vitiated our tests slightly. But I do not think that this can account entirely for the large discrepancy between the theoretical figures and the figures obtained by test. It seems to me that the lower breakdown spark-over voltage of large spheres, as compared with small spheres, must be due to some external effect. Perhaps it is a question of free ionization in the air; it seems probable that the largest sphere collects its electrons and positively charged molecules from a very much larger volume of space than the smaller spheres. The positive charges will be drawn toward the electrode that happens to be negative at a certain instant, and the negative will be drawn toward the positive. While these charges do not cause immediate breakdown, their presence will increase the intensity at the surface they will tend to accumulate at the point of highest potential gradient and finally, on the largest spheres, increase the intensity sufficiently to cause spontaneous ionization.

Referring to the paper by Messrs. Whitehead and Gorton, their modification of the method first used by Mr. Chubb and myself, to meet the exigencies of the high-frequency test, is very interesting, but there is a question in my mind whether the rectifier does not produce superimposed oscillations of its own. In other words, as I see it, in their circuit, they introduce what amounts to a square-topped alternating wave which has an infinite number of frequencies. It is possible for conditions to arise such that any one of this infinite number of harmonics may resonate, causing a high peak in the voltage, which may be of such frequency and characteristics that its true value is not properly recorded.

Another possibility of error suggests itself to me in Dr. Whitehead's tests. I do not think it safe to assume that the rotating field of the generator has sufficient inertia to prevent it from causing troubles due to surges in the supply circuit. Our experience in the first calibration of the sphere spark gap showed that even with an armature running at very high speed, supplying alternating current to the testing transformer, the effect of surges in neighboring circuits was noticeable—we had a neighboring three-phase grounded crane circuit, in which heavy loads were suddenly applied, and we found this had a great effect on our testing voltages. Every time the crane hoist started, we would have a breakdown and oscillation, in spite of the fact that the two systems were connected only through mechanical parts having considerable inertia. The reason, as I understand it, is that any slight oscillation in the mechanical part will set up an oscillating voltage, which may in itself be small, but under certain circumstances the oscillation may have the same period as the test circuit, and cause quite high oscillating voltages.

Probably either of these two possibilities may explain the results that Dr. Whitehead found—namely, that at certain definite points there was an apparent discontinuity in the corona point.

In connection with the question of resonance in transformers, we had some experience which led us to try to find some way of getting an absolute method of measuring maximum voltage without having recourse to ratio. Our shop testing force had an experience several years ago with a high-voltage transformer which was to be tested for certain overload capacities. They could not get the transformer past the testing floor. Every time they tested it by the ratio method, they failed. For some reason or other it never occurred to them to use the sphere gap to find out what was the trouble. I was asked to go down and investigate the matter. I suggested that we try to see what the sphere gap showed. We found in the case of one generator a test value above that shown by ratio all the way from zero to 60 per cent on the high-tension side, purely due to wave distortion and resonance of the distorting harmonic. It is never safe to trust to ratio on tests with very high-voltage transformers, on account of the fact that the capacity of the transformer is necessarily quite large.

Referring to the paper by Messrs. Clark and Ryan, I wish to ask the authors if they assume that the wave form of an oscillating circuit is so close to a sine wave that it cannot affect the maximum value of the voltage. We have had waves of applied voltage that looked like almost perfect sine waves, which gave waves of charging current with condensers which showed distinct harmonics. The multiplying factor of the higher harmonics is very large, so that even a very small fraction of a normal frequency would be magnified and multiplied, through resonance, enough to have a large effect on measurements, resulting in large discrepancies from the values indicated by ratio.

I note another thing in the paper by Messrs. Clark and Ryan, and that is that their spheres are isolated, and they have no distinct zero potential point in their system. In such a case we have no idea what the relative potentials of the spheres are. The whole system may oscillate at a high frequency above zero, so that the maximum intensity at the spheres of such a system is quite indefinite. For that reason, I am inclined to think that these tests cannot be considered as final.

A point Messrs. Clark and Ryan bring out in their paper which I think is very important, is the question of the weight to be given in test measurements in connection with such a piece of apparatus as the spark gap; the sphere gap particularly. In studying the sphere gap, it has a maximum breakdown, which is the voltage we wish to arrive at. Our tests are possibly subject to extraneous conditions, such as surges in neighboring circuits, etc., and also to fluctuations, breakdowns due to the oscillation and consequent fluctuation, but if measurements are carefully carried out, it is not possible to obtain values higher than the actual breakdown voltage. So that in using the results of such tests the average of a large number of tests is not necessarily the correct value, but rather greater weight should be given to the maximum values, in other words, any discrepancy will be of lower value than the actual true strength, and is probably due to the oscillation or some trouble in the circuit itself.

Referring to the maximum voltage meter, as I have called it—the method that Dr. Whitehead has used and which Mr. Chubb and I used in the original paper on the calibration of the sphere gap—I may state that it gives what may be called the average maximum value. In other words, it cannot show the maximum value that may occur at any one cycle, due to some external effect; if there is a difference in the positive and negative wave form, or change, during a very short length of time, this cannot be shown. It simply indicates the average of a consecutive series of waves of charging current, and gives the average maximum value of applied voltage for the consecutive series. In order that this shall be the true maximum value, it is necessary to presuppose a steady and constant applied voltage and a constant secondary voltage.

The vibration of the suspended wires, mentioned in the paper by Messrs. Whitehead and Gorton, I have also observed at corona points on wires with neighboring large bodies.

D. D. Ewing: I believe we all realize that one of the greatest difficulties we have to encounter in the study of high-tension phenomena is the difficulty of making the measurements with any degree of scientific accuracy. The points I have in mind were brought up by Dr. Whitehead's paper. I believe Mr. Fortescue, if I understood him correctly, touched on one of them, namely, the deformation of wave form when the mercury arc is used as a rectifier. I notice that Dr. Whitehead in his experimental work made use of a direct-current measuring instrument, presumably of the permanent magnet moving coil type. He states in his paper that the permanent magnet type instrument is suitable for the purpose although he does not specifically state that he made use of this particular type of instrument. I would like to call attention to the fact that some of the common commercial forms of this type of instrument can not be relied on to give a very high degree of accuracy, when used to indicate the average value of a fluctuating quantity. In some tests made several years ago, on some meters used in railway service, I found that the average value was about 15 per cent off. In the measurements made by Dr. Whitehead, the errors introduced by the use of the mercury arc and this type of instrument would be differential rather than cumulative, thus giving a low resultant error. I wish, however, to call attention to this fact about the direct-current permanent magnet instrument: it must be used with caution if the quantities are fluctuating rapidly.

E. E. F. Creighton: I think the most evident thing in all these papers and in all the discussions which have taken place in the past few years has been the lack of some instrument or some device that will accurately measure the voltage. If such an instrument were available at the present time, the whole subject could be cleared up.

Every one of these papers adds a little more, makes one step nearer the final solution, by giving the results of some method which has been tried out for the measurement of voltage at high frequency. We have endeavored in the study of lightning arresters for many years to get something we could rely on. Our endeavor has been, not so much to locate a condition and measure the voltage, but to vary all the conditions and get the minimum gap length as near as we could for the same voltage impulse applied.

In working with Alexanderson's alternator, running up to 200,000 cycles per second, one of the first difficulties encountered was the impossibility of getting any definite voltage ratio in the transformer. We had a transformer made up of eleven layers, and used one layer as a primary and the other ten layers as a secondary, stepping up 1 to 10. We found at a certain frequency when 100 volts was applied to the primary we got 100 volts across the secondary. Instead of getting 1 to 10, according to the ratio of turns, we had a ratio of 1 to 1. Then we took our voltmeter and applied it to the different layers, and found one layer that was given a ratio of ten times the impressed voltage, in other words, 1000 volts, where the ratio of the number of turns was only 1 to 1. This simple illustration shows the effect of internal capacity in entirely changing the voltages that should be given by the ratio of the number of turns.

In regard to the free ionization in the air, we have had by tests in the laboratory a number of illustrations of this ionization effect. The vacuum arrester consists of a copper tube with an insulated electrode on the inside and more or less vacuum produced around these electrodes, depending on the spark voltage desired. The gap length is of the order of 1 mm. and the diameter of the tube only about $\frac{3}{4}$ in. (about 19 mm.). When potential is first applied the sparking voltage may be 500 volts. If potential is applied immediately afterwards a lower value is needed to cause a spark—even as low as 350 volts. It requires considerable time, a number of minutes, in some cases a number of hours, for this internal ionization to disappear.

Another case of ionization was illustrated in the test we showed before the Institute something over a year ago, in which we recommended the use of high frequency for the testing of insulators, it is shown in all of these tests that when high frequency is applied to an insulator there are obtained many sparks that are fairly evenly distributed around the surface of the insulator. These sparks are not simultaneous, but successive. The explanation of the distribution may be that when the potential is applied to the cap of the insulator it ionizes more or less evenly the atmosphere all over the surface of the porcelain. Due to accidental conditions, the first spark will break over at some one point. In so doing, it will relieve the stress in the atmosphere at that point. The subsequent sparks will find points in the atmosphere elsewhere that are highly ionized and the subsequent sparks will consequently take other paths. I think this is another illustration of the fact that ionization may reside for a considerable time in the atmosphere.

Professor Caldwell brings up a very pertinent question, that is, in using resistance in series with spark gaps, is the testing outfit still applicable for the testing of apparatus? While series resistance is desirable as recommended, there is a special condition where it is not applicable. It is not applicable to the testing of lightning arresters. A series resistance of one ohm per volt will give erroneous results in the testing of arresters. We have used for many years without series resistance a transformer at 100,000 volts for testing work, and in only two cases during all that time have oscillations been produced which damaged the end turns.

Mr. Peek has brought out definitely that moisture in the atmosphere causes an increase in the spark potential of a needle gap (but not of a sphere gap).

It may be of some interest to note that in the testing of multigap lightning arresters the opposite effect is sometimes found. For example, a compression chamber lightning arrester tested on a perfectly dry day had a certain sparking potential. Three days later on a humid day and without any changes in the circuit the spark potential was considerably lower. From a certain point of view, that is a valuable thing to know. When lightning is about to take place, the arrester will be a little more sensitive.

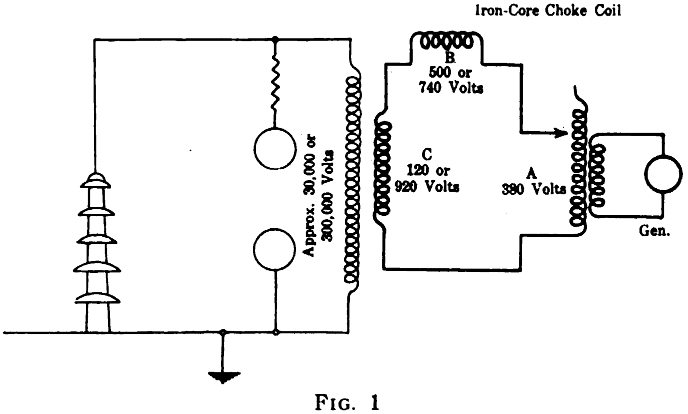

Fig. 1

H. B. Dwight: In Mr. Peek's paper are given various precautions to be observed in making high-voltage tests. Although the list was not meant to be complete, I would suggest adding to these the avoidance of the use of choke coils with iron cores, even in the low-tension circuit. There is a tendency to use such coils in practical testing because small transformers or autotransformers are generally available in many sizes, while air coils are not. The iron-cored coils may not always produce trouble, but there is distinct danger of it, as is shown by the following experience encountered in routine commercial testing.

In testing some insulators at 300,000 volts, an iron-cored choke coil was used as at *B*, Fig. 1. On applying a low-tension voltage which normally gave about 130,000 volts, an entire absence of corona was noted. On again closing the switch with exactly the same connections there was a heavy continuous discharge over the insulator, indicating much more than 130,000 volts. Repeated closing of the low-tension circuit gave sometimes one and sometimes the other of these two steady conditions.

In locating the cause of this trouble, it was found by measurements of the voltages on *A*, *B* and *C* that the voltages on the insulator in the two steady states were about 30,000 and 300,000 and that the choke coil was in the one case unsaturated and in the other case, saturated. Which state was produced depended apparently on the part of the voltage wave at which the circuit was closed. Both states were steady except that sometimes the first would suddenly change into the second, with corresponding increase in voltage.

The vector diagrams for the two different steady states with the same applied voltage of 380 volts, are shown in Fig. 2.

An indication of how the saturation of the iron core produces the erratic results is shown in Fig. 3. The curve of applied voltage is to be calculated from the capacity of the insulator and the magnetizing current and iron loss current of the choke coil. For details of this calculation see the *Electric Journal*, p.1102, December, 1911. The current and voltages have been observed with an oscillograph and have been found to have the same frequency as the generator, and to have phase relations in agreement with the vector diagrams.

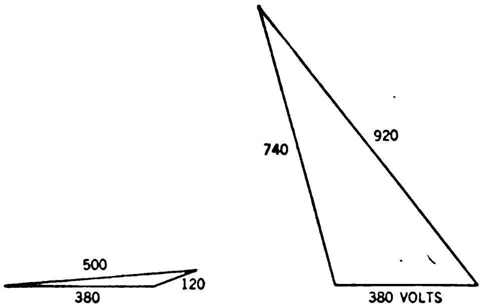

FIG. 2

The phenomenon is essentially a low-voltage, standard frequency phenomenon of continuous duration. It has no connection with the high-frequency oscillations which occur around a spark gap and it is quite distinct from the phenomenon of simple resonance. The two different voltages obtained from one connection of apparatus depend on the combination of leading current and an iron magnetic circuit which becomes saturated. It is seen, from Fig. 3, that a certain value of applied voltage may correspond to two different values of amperes, according to a point in the part *U R*, or the part *T S*, of the curve for applied voltage. These two values produce two different values of voltage on the testing transformer, the curve for which is seen to be in two parts, separated by an unstable region.

In investigating this phenomenon, the applied voltage may be slowly increased from *U* to *R*, and then the current will suddenly change from *R* to *S*. Thus, about ten times as much current will flow through the choke coil, and a high voltage will be produced. Then, on lowering the voltage gradually from *S* to *T*, the current drops suddenly from *T* to *U*, and the original condition is obtained.

Since a choke coil with an iron core may render indeterminate the voltage to be obtained from a given arrangement of apparatus, and may give suddenly a far greater voltage than would be expected, its use would appear to be inadvisable.

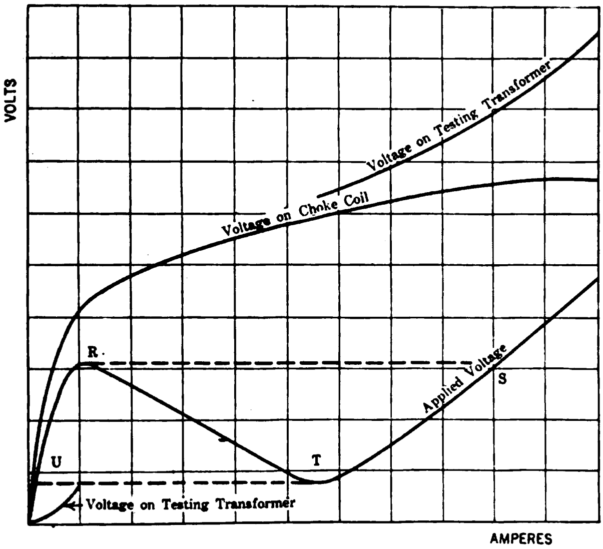

FIG. 3

W. W. Lewis: Mr. Peek says that carbon or graphite rods should be avoided as resistance in series with the sphere gap, because they are unreliable. We have found in Pittsfield that this is usually true with the so-called "high-rated" carbon rods, that is, rods that are rated in the neighborhood of 60,000 ohms each, because these rods contain very little carbon; they are composed of some kind of clay mixed with graphite, and their resistance changes when current is passed through them. The "low-rated" rods, *i.e.*, rods rated in the neighborhood of 4000 ohms each, we have found to be very constant and reliable. We have checked these by measuring the voltages set up in the high tension of the transformer under test, when the spark gap is arced over as shown in Mr. Peek's Fig. 13, and we find that we get no appreciable voltage set up in the high tension of the transformer when resistance is used to the value of one ohm per volt or over. We have also run heat tests on these rods and find their resistance to remain constant, whereas that of the high-rated rods increases appreciably.

We have tried metallic resistance and find that in order to get high resistance, very small wire must be used, and to prevent this burning out, it must be immersed in oil. It is very difficult to prevent the oil from leaking and to insulate the resistance properly. Water resistances are subject to the trouble that steam forms at the terminals and the water explodes violently from the tubes. We have decided that altogether the low-rated carbon rods are nearest to the ideal.

Mr. Peek in his precautions says: "The spheres should be twice the gap setting from surroundings." It is rather indefinite as to just what this means. We have interpreted it at Pittsfield to mean that no part of the wooden supporting standard or metal shank bushings shall be nearer to any point of the spheres than twice the maximum gap length. When you figure on 75-cm. spheres, which we have at Pittsfield, and allow a distance of 150 cm. from the supporting standards to the spheres, and 75 cm. as the maximum gap, this gives 525 cm., or about 17 ft., between sphere gap standards, and this means a great expense in treated wood and in floor space.

I understand that the new Institute rules are more lenient in this respect, reading that "No extraneous body or external part of the circuit shall be near the gap within twice the diameter of the spheres." With the 75-cm. spheres, the distance between standards would be, according to this rule, 375 cm. or about 12 ft. The rule might well be further modified, a distinction being made between bodies that are insulating, and metallic bodies.

We have made a few tests recently to check the effect of wood, metal and porcelain on the sphere gap arc-over, when these objects are placed at different distances from the spheres, and we find that wood and porcelain have practically no effect when placed as close as one-half the gap distance away from the spheres. Metal, however, appreciably reduces the spark-over, that is, when a sheet of metal was placed one and one-half times the gap distance away from the spheres, the spark-over voltage was reduced four per cent.

Mr. Fortescue questioned the statement in regard to the effect of metal on the shanks. To check this we made some tests, placing a disk of a diameter equal to the diameter of the sphere (12.5 cm.) on the shanks at different distances from the sphere, and we found that when this disk was placed on the shank of the non-grounded sphere (these tests were all made with one sphere grounded) it made as high as 3 per cent difference on the spark-over. These values were checked several times, the voltages being determined by a voltmeter coil placed in the center of the high-tension winding of the testing transformer. We have found the voltmeter coil to be very accurate and valuable for this kind of work.

E. P. Peck: I want to ask Mr. Peek what he meant by saying, on page 911, " For steep wave fronts a higher voltage is required to spark over a given gap than for low frequency." The rest of the paper indicates that the higher the frequency the lower the spark-over. This one remark indicates the other direction.

J. R. Craighead: A previous speaker mentioned the practise of using the voltmeter coil in the middle of the transformer as a means of reading the voltage, and at the same time spoke of using one of the spheres as grounded. Now, it sometimes becomes convenient to ground the transformer in the middle when the voltmeter coil is there, to protect the voltmeter coil. I would ask Mr. Peek if he can tell us anything about the relation of this to the grounded curve and the ungrounded curve. Also, what is the effect of the ground placed at some other point in the circuit?

E. W. Peek, Jr.: Mr. Chubb states that after a given high voltage is reached, spark-over will result between spheres no matter how far the gap length is increased. In other words, the law which I have given suddenly ceases to hold. The curve becomes discontinuous.

Theory at once explains this discrepancy, when the cause may be readily corrected or removed in *practise*. The curve is really continuous. The reason for the discrepancy is as follows:

The spheres with their connecting leads make up a circuit of capacity and inductance. A local spark-over or static spark on a section of a supporting bushing, from the end of a connecting wire, etc., will cause a readjustment of energy distribution in the circuit. An oscillation or high transient voltage results, which is superposed upon the applied voltage and causes the sphere gap to spark over. The actual voltage at the sphere gap may thus easily be double the applied voltage, or the voltage read at the meter. The sphere gap may thus, under this condition, be lengthened out to a considerable extent, or to the limit of the transient voltage, and spark-over will result. The sphere measures the transient voltage and not the applied voltage. The applied voltage at which the curve appears to become discontinuous, is the critical voltage for local breakdown somewhere, as on leads, etc. The transient follows. The effect may be easily reproduced in the laboratory at fairly low voltages. It is more likely to occur in practise at high voltages because static sparks are most likely to occur at high voltages. The remedy is to arrange leads and conductors so that local static sparking does not occur and so that the gap supports are insulated to withstand the voltage to be measured. The resistances should be placed directly in series with the gap and as near the spheres as possible. The sphere gap is much more sensitive to transient voltages than the needle gap. Care must always be taken to prevent these voltages reaching the gap, unless it is desired to measure them.

As an example: A sphere gap without series resistance was placed in parallel with a string of insulators, and voltage applied. The known arc-over of the insulators was 300 kv. The sphere gap was set for that voltage. At 295 kv. static sparks occurred on the insulator unit near the line end. The sphere gap sparked over, due to the resulting high transient voltage, and relieved the pressure. The gap was lengthened. At 295 kv. the transient again occurred and caused the sphere to spark over. It was in this way necessary to increase the sphere gap to a spacing equivalent to 400 kv. before the insulators sparked over. The spheres in this case measured the transient voltage. In such tests it is preferable to use the spheres only to calibrate the wave shape and transformer ratio. This should be done at a voltage below that at which static sparks appear on the insulator.

We have, since the paper was written, actually checked a calculated curve for 75-cm. spheres up to 700 kv. with good agreement. It was, of course, necessary to use a very well insulated stand and leads, etc., at this voltage.

The effect of altitudes must be the same at high voltages as at low voltages. At high voltages the spacings are greater than at low voltages; the resulting gradients upon which the breakdown depends are the same. In my former papers I have shown that the decreased strength of air at high altitudes is the result of decreased air density, and that the effect is the same whether the change in density is due to temperature or to pressure.

Mr. Dwight's discussion is interesting. I should like to see the data.

The term "high frequency" is at present very loosely used and under it are included continuous high frequency, and transient voltages, as oscillations, steep wave front impulses, etc. The effects of these are naturally quite different. There are, in this way, many apparent discrepancies in the effects resulting from the "same" cause—"high frequency." The term is thus used to explain many "mysterious" failures. The sphere gap, when the maximum spacing is limited to the diameter of the spheres, measures with fair approximation high frequency, and transient voltages. In case of high frequency care must be taken to polish carefully the surface of the sphere. The needle gap does not even approximate such voltages. At continuous high frequency the needle gap curve is changed by the intense local heating; at steep wave front by the limited time. This is discussed in my paper. I have given a theoretical explanation in former discussions.* It may be of interest to give an example of impulse voltage here:

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*August, 1914, PROCEEDINGS, page 1200.
"High Voltage Engineering", *Journal* of Franklin Institute, Dec. 1913.
October, 1914, PROCEEDINGS, page 1653.

Spacing of Needle cm.	Voltages Required to Cause Needles to Spark Over			Ratio	
	60 cycles max.	Impulse voltage (measured by 25-cm. spheres using 60 cycle curve	Impulse voltage calculated from circuit constants	Calculated impulse voltage 60 cycles	
				Needles	Spheres
2.3	26.0	36.6	39.5	1.41	1.08
3.95	39.5	59.5	60.5	1.45	1.02
5.34	51.5	73.5	74.5	1.45	1.01

A higher impulse voltage is required to cause the needles to arc over than at 60 cycles. The spheres arc over at approximately the same voltage at 60 cycles and impulse. This particular impulse reached its maximum in 0.00045 milliseconds. A steeper impulse would require a still higher voltage on the needle gap to cause arc-over; with continuous high frequency the needle sparks over at lower voltages than at 60~. Great caution is thus necessary in making "high frequency" tests. Much damage may also be done to apparatus, etc., as I have pointed out, unless tests are made with caution. Care should be taken to place the spheres at a considerable distance from ground and from large metal, or other conducting masses. In no case should this distance be less than twice the sphere diameter. This is so whether both spheres are insulated or one sphere is grounded. The curves for both spheres insulated were made with the neutral at midpoint. To be sure of this, it is desirable that the transformer neutral be grounded. Carbon rods may be made in which the resistance is not greatly affected at high voltages, but rods as generally made are affected.

Dr. Whitehead has developed an extremely interesting method of measuring high-frequency voltages. I have also noticed the phenomenon of vibrating wires which Dr. Whitehead mentions. Photographs showing this are given in my 1912 paper.

Referring to Fig. 5, in the paper of Messrs. Clark and Ryan, I would like to call attention to the fact that at small spacings the 60-cycle curve is also approximately a straight line. At higher voltages the high-frequency curve will bend as the 60-cycle curve does. For 7-in. (17.8-cm.) spheres, curve III will fall closer to I and II.

John B. Whitehead: It is interesting to ask, in connection with this question of frequency, to what conclusion these papers lead us. Considering the ascending range, there is evidence from our experiments that with increasing frequency there is a slight, but certainly evident, lowering of corona-forming voltage. There have been one or two suggestions, by Mr. Fortescue and others, of possible sources of error, and at first glimpse it appears that these errors, if they exist, would be in the direction of lowering the apparent corona voltage. In my opinion, however, these errors are not present.

In Mr. Peek's range of frequency, up to 40,000 cycles, a further lowering is indicated; and then going up to the maximum range, Professor Ryan has a still further lowering. In the case of oscillating circuits, long associated in our minds with brush discharges, it would not be an astonishing thing to find that at higher frequencies we would have lower corona-forming voltages. At the same time, high values of peak voltage which cannot be detected often occur in oscillating circuits, so it is not necessarily the case that we must have a lower corona voltage in a high-frequency circuit, simply due to the higher frequency.

In Mr. Peek's description of the experiments at 40,000 cycles, he suggests that if his spheres had been more carefully cleaned he might have gotten a discharge voltage which would be more nearly that observed at commercial frequencies. He also measured his voltages, as I understand it, with an electrostatic voltmeter. Although he states that correction has been made for wave form, the static voltmeter measures effective values and it would be interesting to know how he has applied correction at these frequenceis.

The observations reported in the paper by Messrs. Clark and Ryan, as to the ratio of lowering at still higher frequencies, show a remarkable lowering of corona voltage. It is to be hoped that Professor Ryan will repeat some of his interesting experiments and corroborate the present results beyond question.

Summing up the three papers, there is a distinct evidence of lowering of the corona voltage with increasing values of the frequency. The amount of that lowering is apparently small, except possibly at very high frequencies. For these high frequencies more observations are desirable.

With reference to Mr. Fortescue's suggestions as to possible errors in our observations due to the presence of the mercury gap and the inertia of the generator, we did not use the mercury arc itself as a rectifier. Our two mercury arcs were excited by independent continuous-current circuits, and we had the auxiliary electrodes in the mercury tube, simply using the very copious ionization which is always present in a mercury arc as a conducting path which had, of course, only unipolar conductivity. The very small current carried, and the fact that the tube was in series connection, indicate oscillation as a very remote possibility. At the same time, the suggestion is possibly an explanation of the unstable conditions in the region near 400 cycles where we found evidence of resonance.

The inertia of the generator was simply mentioned as one of the factors which led us to believe that we had stable conditions,

conditions which were uniform at all times, and our observations were repeated so definitely throughout that there is hardly a chance for error on account of the possible fluctuation of the mass of the armature.

In reference to Mr. Ewing's comment on the possible error in using a permanent magnet type of instrument for recording average values, this type of instrument has been used for taking average values ever since the days of the first contact makers for measuring wave forms. It would be interesting to know for what range of pulsations Mr. Ewing made his observations. We are, of course, working here up between one thousand and three thousand cycles, far above the highest commercial frequencies.

Before closing the meeting, I would like to report an experiment which has recently been made abroad, the news of which has come to me in a letter. It is a matter of very great interest and with your permission I will take about five minutes to tell you about it. There has been no official publication of it as yet, but the publication will follow, and the word that comes to me from one of my colleagues who was present, and saw the experiment, is what I wish to report to you.

We are all familiar, of course, with the mechanical analogies that are drawn between electric circuits and the motion of masses, in which we consider inductance as mass, capacity as elasticity and resistance as the friction in a mechanical system. If we follow this analogy, and hark back to one of Newton's laws, that a body will persist in its state of motion unless acted on by some external force, it will explain the experiment in question. If we could realize mechanically the motion of a body absolutely free from all friction, the body would go on moving indefinitely.

Professor Kamerlingh-Onnes of Leyden has produced the current which does not die out, and which is not excited by any electromotive force, thus realizing the analogue of the moving mass free of all friction. The experiment is briefly this: He takes a coil of fine lead wire of about 1000 turns, and about 2 cm. in diameter, and short-circuits it on itself. This coil is placed in a strong magnetic field, the lines of force threading this round coil. A vessel of liquid helium is brought up so that the wire may be immersed in it, while still remaining in the magnetic field. The liquid helium sets up temperatures which are far lower than any temperatures we have known, even lower than the temperatures that may be got from liquid air and liquid hydrogen, temperatures which are at least in the neighborhood of the absolute zero. If you take curves showing the relation between the specific resistances of material and temperature, these curves for all substances are all straight lines and all tend down to the absolute zero, indicating that the resistance would become zero if the temperature were extended to the absolute zero. The liquid helium brings us nearer to it than we have ever been before. Now, with the helium, we have a coil of lead wire in a strong magnetic field, and at a temperature, we will say, in the neighborhood of absolute zero, minus 273 deg.

Under these circumstances the circuit of the exciting magnet is broken, inducing an electromotive force and consequent current in the short-circuited coil, which is near absolute zero, and therefore near zero resistance. Consequently, there is no frictional element, no damping factor, if you please, and the current should go on indefinitely since the coil has no resistance. It went on during a period of four to five hours, which was stated as the time of observation of my friend. There was no indication of a diminution of the current in that coil at the end of from four to five hours.

M. G. Lloyd: What was the evidence that the current was continuing?

J. B. Whitehead: It was not stated. The exciting circuit was broken, and the exciting magnet removed. I should imagine the evidence would be the influence of the coil on a magnetometer needle. It seems the most obvious way.

W. B. Kouwenhoven (communicated after adjournment): The three excellent papers presented under the auspices of the Electrophysics Committee all had to do with high voltages, and in all of them the accurate determination of the voltage plays a very important part. I wish to bring to the attention of the members a method for measuring the effective value of alternating-current voltages, which has a very high degree of accuracy. This method consists, briefly, in using a high resistance connected in series with a small resistance across the high-voltage terminals, and measuring the drop of potential across the small resistance with a quadrant electrometer.

Suppose that a high resistance R and a small resistance r be connected in series across a potential difference of V volts, and that the drop of potential across the small resistance is v. Then $V = \frac{R + r}{r} v$. This method, when used for direct current and low voltages, is simple and accurate. When applied directly to alternating currents and high voltages, however, it is no longer accurate, because of the capacity currents which flow not only from the resistances to earth but also between the different parts of the resistances. On account of this the current passing through the resistances can no longer be considered as quasi-stationary; the ratio

$$\frac{V}{v} = \frac{R + r}{r}$$

holds no longer, and the voltages in different parts of the resistances are in phase neither with each other nor with the total voltage. It is possible, however, so to construct the resistances that the inaccuracies are eliminated.

Let us consider such an arrangement of resistances theoretically. Suppose that the large resistance be divided up into n units or divisions R_1, R_2, R_3, ... R_n, and that these are so small that we may consider the current in each to be quasi-stationary, and that the current in going from division to division changes slightly in value and in phase. This arrangement is illustrated in Fig. 4. One terminal of the high voltage is connected to the resistance division R_n and the other to R_1 and at the same time to earth. Now in R_n the capacity currents to earth are the largest and these currents are ahead of the total voltage in phase. Therefore the voltage drop v_n in this resistance unit leads the total voltage V. The voltage drops in the various resistance divisions and the total voltage form a polygon as shown, and it follows that the voltage drop in R_1 lags behind the total voltage. Voltage measurements are

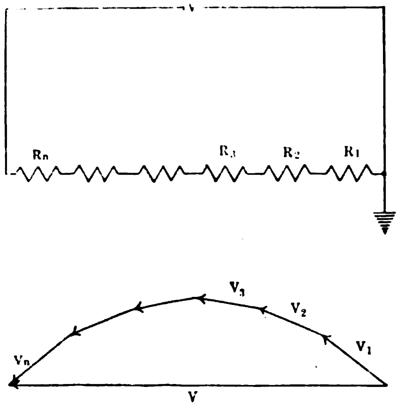

FIG. 4

usually carried out at the earthed pole and the problem resolves itself into bringing the current and voltage in R_1 into phase with the total voltage, and in determining the value of the ratio between V and v.

A set of eight resistance units based on this principle was built in the laboratories of the Reichsanstalt, Germany. The German resistance units were wound with manganin wire; the maximum voltage drop per unit, without over-heating, was 3000 volts. I built a set of resistance units using a liquid resistance as a substitute for the wire resistances in order to determine if, by so doing, it was possible to increase the voltage range of the apparatus and to use an electrolytic resistance for this purpose. The electrolyte was the so-called Manganini solution, and proved very successful.

Each resistance unit consists of a Jena glass tube which contains the solution. These tubes are about a meter in length, have a diameter of approximately 1 mm. and are fitted with expanded ends to allow room for the electrodes. With tubes of these dimensions it is possible to construct a resistance unit of 24 million ohms per meter length. In order to define the capacity to earth, each tube is fitted with a metal cylinder slightly longer than the tube and of 10 cm. inner diameter. These cylinders are well insulated from the Jena glass tubes and the entire arrangement may be regarded as a cable whose central conductor has a high resistance per unit length. In order to bring the current at the earthed pole into phase with the total voltage V, it is necessary to apply a voltage to the metal cylinders such that there will exist a certain definite difference of potential between the earthed end (end of tube nearest earthed connection) of the tube and its protecting cylinder. The so-called telegraph formulas of Maxwell apply to a cable of this construction, and, by solving them, it is possible to ascertain what this potential difference should be.

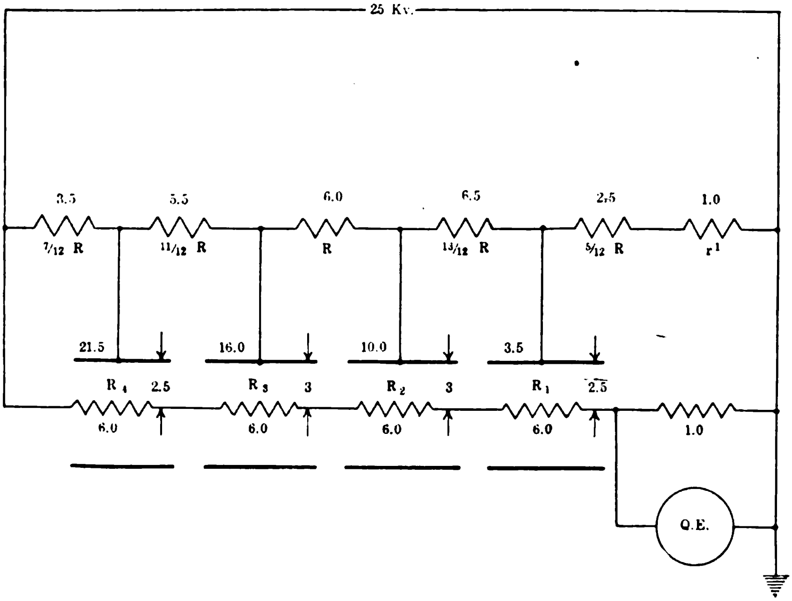

FIG. 5

The Manganini solution or the $\frac{2}{3}$ normal manitol, boric acid, calcium chlorid solution was used as the electrolyte. According to Maltby[1] this solution contains:

manitol	121.1 grams per liter
boric acid	41.2 grams per liter
calcium chlorid	0.06 grams per liter.

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[1] Maltby, *Zeitschrift. f. Ph. Ch.*, 18, S. 133, 1895.

To this solution I added one part of distilled water. Under these conditions the solution has a conductivity of about 0.00044 and between the limits 17 deg. and 24 deg. cent. the change in the resistance is less than 1/10 of one per cent.

The electrodes were of platinum and were plated with spongy (black) platinum in order to reduce the polarization to a minimum. The phase displacement due to the polarization was measured and found to be about two seconds of arc at a frequency of 50 cycles and with a current density of from 0.3 to 2.0 milliamperes per sq. cm. of electrode surface.

The resistance set which I built consisted of four resistance units. The set has two circuits, a main circuit, which consists of four resistance units, and a secondary circuit, which supplies the metal cylinders that protect the resistance units with voltage. Nine tubes in all were used, four in the main and five in the secondary circuit.

In Fig. 5 it has been assumed that a voltage of 25 kv. is being measured. The main circuit, which contains the four resistance units and a resistance r across which the quadrant electrometer is connected, is shown at the bottom part of the figure. The 25 kv. is supposed to be divided in this circuit as follows:

In the resistance r there is a voltage drop $v = 1$ kv.
“ “ “ unit R_1 there is a voltage drop $V_1 = 6$ kv.
“ “ “ “ R_2 “ “ “ “ “ $V_2 = 6$ kv.
“ “ “ “ R_3 “ “ “ “ “ $V_3 = 6$ kv.
“ “ “ “ R_4 “ “ “ “ “ $V_4 = 6$ kv.

The total voltage in the main circuit is $v + V_1 + V_2 + V_3 V_4 = 25$ kv. The metal cylinders which protect the resistance units and give them a definite capacity are shown by the heavy black lines. The secondary circuit which supplies the proper potentials to these cylinders is seen in the upper part of the figure. In order to provide the correct potentials the resistances in the secondary must be of different sizes. In the secondary circuit the voltage is divided as follows:

In the resistance r' there is a voltage drop of 1.0 kv.
“ “ “ 5/12 R there is a voltage drop of 2.5 kv.
“ “ “ 13/12 R “ “ “ “ “ “ 6.5 kv.
“ “ “ R “ “ “ “ “ “ 6.0 kv.
“ “ “ 11/12 R “ “ “ “ “ “ 5.5 kv.
“ “ “ 7/12 R “ “ “ “ “ “ 3.5 kv.

The total voltage in the secondary circuit is 25.0 kv.

The potential differences between the tubes in the main circuit and their protecting cylinders are also shown in the figure. There are, for the end resistance units R_1 and R_n (in this case R_4), 5/12 of the voltage drop per resistance unit or 2.5 kv.; for all other resistances R_2, R_3, ..., $\frac{1}{2}$ of the voltage drop per unit or 3.0 kv. The tubes or resistance units in the main circuit are all of the same size and have been designated by the letter R. The tubes in the secondary circuit are of various sizes, which have been given in terms of R, thus: $5/12\ R$, $7/12\ R$, etc.

With this set it is possible to measure voltages as high as 27,000 volts with all four resistance units in the main circuit, but for lower voltages it is advantageous to use fewer tubes. I should recommend the following combinations of the resistance units:

Up to 6000 volts, one resistance unit, and, in the secondary circuit, resistances $5/12\ R$ and $7/12\ R$, and $r = r'$.

From 6000 to 12,000 volts, two resistance units, and, in the secondary circuit, resistances $5/12\ R$, R and $7/12\ R$, and $r = r'$.

From 12,000 to 18,000 volts, three resistance units, and, in the secondary circuit, resistances $5/12\ R$, $13/12\ R$, $11/12\ R$ and $7/12\ R$, and $r = r'$.

From 18,000 to 24,000 volts, four resistance units, and the entire secondary circuit, and $r = r'$.

For voltages much above 24,000 volts, extra resistance units must be added to the main circuit, and also in the secondary circuit an extra resistance R for each unit added to the main circuit.

Tests of the resistance set that was built from resistances wound with manganin wire were made[2] at the Reichsanstalt, Germany, and I carried out a series of tests[3] on the set that I built with the electrolytic resistances. These tests showed that the theoretical assumptions were correct and that the voltages measured were accurate to within ½ of one per cent.

It should be possible to use eight of these electrolytic resistances in series without over-stepping the theoretical limits for accuracy, thereby increasing the range of a single set to approximately 50,000 volts. With two such sets connected in series and grounded at the junction point, voltages of twice that magnitude could be handled. The use of the electrolytic resistances for high-frequency work possesses the advantage that they are free from self-induction, and with increasing frequency the polarization would disappear entirely.

Three voltage transformers were tested for the constancy of the ratio of transformation. The primary voltage was measured in each case by a Weston a-c., d-c. voltmeter. The ratio of transformation was found in every case to be constant to within one per cent from about half voltage to full rated voltage of the transformer. For low voltages, however, the ratio of transformation gave results that were in some cases as much as four per cent too high, the error decreasing more or less gradually as half rated voltage was approached. Therefore investigators should be very careful when making high-voltage tests not to rely too much upon the ratio of transformation.

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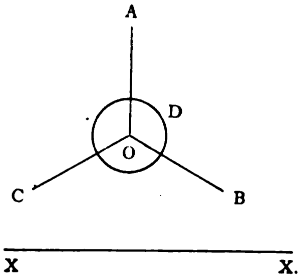
[2] Orlich and Schultze, *Archiv. f. Elek.*, 1, S. 1 and 88, 1912.

[3] Kouwenhoven, *Washington Univ. Studies*, Vol. 1, p. 143, 1914.

DISCUSSION ON "THE EFFECT OF DELTA AND STAR CONNECTIONS UPON TRANSFORMER WAVE FORMS" (CURTIS), SPOKANE, WASH., SEPTEMBER 10, 1914. (SEE PROCEEDINGS FOR AUGUST, 1914.)

(*Subject to final revision for the Transactions.*)

P. M. Lincoln: We may represent a three-phase system as in this diagram, in which the figure ABC may be assumed to rotate around its center O. The instantaneous voltages will then be proportional to the lengths of the projections upon a line, as XX. For instance, at the instant represented in the figure the instantaneous voltage of leg AO is zero, that of phase CB is a maximum, and those of phases AB and AC are each one-half of the maximum, one increasing and the other decreasing.



If we so represent a three-phase system, we will find that a third harmonic in the leg voltages OA, OB and OC will have the effect of causing the neutral point O to rotate around the small circle D and the rate of rotation of the neutral around this small circle will be three times that of the whole system around O. For instance, if we assume that the point A has advanced 10 deg., during the same time the neutral will have advanced 30 deg.

The diameter of the small circle D is dependent upon the amount of third harmonic that enters the leg voltages OA, OB and OC. It is evident from this analysis that we may have any amount of third harmonic voltages in these leg voltages without having any third harmonic voltages in the phase voltages AB, AC or BC. This physical conception has enabled me to see this problem more clearly than otherwise and I pass it on for what it is worth.

L. J. Corbett: The paper appeals to me as a very valuable one and one which requires a great deal of study. It brings to light some very interesting problems and I think this idea as given out by our president is very valuable. It is a new one to me. I thought at first he was referring to the unbalancing of load which has the effect of shifting the neutral on this three-phase triangle.

A. A. Miller: It seems to me that this question is open for discussion by the representatives present of the faculties of the several universities and also by the operating engineers. The effect of the oscillograph upon the ability with which we have to diagnose these cases is very marked. Some half dozen years ago there was absolutely nothing of the kind to assist us; the effects of the higher harmonics were guessed at and such results as were acquired, were obtained by means of curves which were plotted more or less from a theoretical basis. By means of this highly sensitive instrument which we now have, we can see exactly what transpires in these circuits.

E. G. Robinson, Jr.: What results are gotten with open-delta connections? I think that is a connection that a great many of us are using to start with on our transformers for power and light; and the question arises in my mind, what is really taking place in your transformers regarding the circulating currents, the triple harmonics and the circulating current in the delta where this delta is open; were these secured with a delta closed or the delta with one side open? I start with an open delta in my transformers and as my load increases, or my power load increases, I close my delta. I would like to have the author answer that question regarding the circulating currents when using transformers with open delta.

M. H. Gerry, Jr.: The old question has arisen of the relative advantages of delta and star connections for power transformers. No general conclusion has ever been reached in this matter, nor is there likely to be any definite answer, as there is no one controlling condition or set of conditions. Certain practises have arisen which have worked well in particular situations. In other places different practises have seemed best. There are so many things to be considered that, after all, the question is one of general expediency.

L. T. Merwin: Along the line of a suggestion already hinted by Mr. Gerry I ask Mr. Curtis, in closing, to answer this question—What form of connection is advisable from the standpoint of the operating engineer for protection of the transmission line beyond the power house, say for voltages ranging from 60,000 and up? The operating engineer is particularly interested in wave forms as well as circulating currents at two points, one between the generators and transformers at the power house and the other between transformers and line. And then again, what bearing has the wave form upon the breakdown point of his transmission line after it has passed beyond the power house? Will the star-delta or the star-star or the delta-star connection give the safest form of wave curve on the line from the standpoint of the breakdown? It is that which interests particularly the operating engineer. Mr. Curtis shows his oscillograph curves with transformer connections open on the high side; but with load on the end of a 150-mile high-tension transmission line, what changes in the wave form will take place as against an open transformer bank?

Livingston P. Ferris: I ask Mr. Curtis to cover the following points in his closure: Just what wave form is considered in the comparisons upon which you base your conclusion? By what criterion do you judge the distortion of wave form characteristic of the different types of connections? Have you followed the recently adopted standardization rules of the Institute or some other standard?

I will mention two circuit arrangements for oscillograms which have been found useful in the investigation of the Joint Committee on Inductive Interference in California. These circuit arrangements are designed to distort the wave form of current through the vibrator, magnifying the higher harmonics in this wave as compared with their relative magnitude in the desired main line current or voltage wave. For current waves, the secondary of a current transformer is closed through a low impedance air core inductance coil, the constants of one such coil being $1.12 + j\,0.0468\,f$ ohms. Around this coil is shunted the vibrator of the oscillograph in series with a condenser and rheostat. The amplitude of the wave and magnification of the harmonics in the vibrator current are controlled by adjustment of the condenser and rheostat in series with the vibrator. An analysis of the vibrator wave expressed in current units, together with a knowledge of the circuit constants, enables one to compute the value of the main line current corresponding to any harmonic. Care is necessary with this arrangement, in order that the impedance in the secondary of the current transformer shall not be too high and particularly that the circuit shall not resonate at or very near the frequency of some harmonic which it is desired to measure. For voltage waves, the vibrator is connected in series with a condenser and rheostat and supplied from a potential transformer. By these methods of accentuating the higher harmonics the accuracy of their determination in the current and voltage waves is much increased.

H. V. Carpenter: I would like to enlarge a little on the point that Mr. Curtis brought out, that the various connections which he dealt with gives different losses in the transformer cores. That would have some bearing in determining the capacities of these different connections, the load capacities. It might be possible if Mr. Curtis has given the matter any thought to tell us something about the amount of increase in rating that might be considered possible in certain cases over that of other connections. It would seem from the hysteresis diagrams which he showed that there might be sufficient saving in core losses there to make it appreciable in the load capacity of the transformer sets.

L. F. Curtis: As to Mr. Robinson's question regarding the open delta: I regret that I have no oscillograms for this connection. I will predict that there will be an unbalance of voltage between the three phases. There could be no third harmonic in any current flowing over a balanced three-phase line, but if there is an unbalance, as would be the case with open delta excitation, there might be a diversity of third harmonic components in the different lines. This would probably produce a reduction of voltage across the open phase, causing the voltage triangle to become distorted, the shortest line representing the voltage across the open side. It would also be probable that the wave forms of voltage of all three phases of the two transformers would be different. It is quite probable that if one wave were flat the others would be peaked.

As to Mr. Merwin's question: Papers which were presented at Pittsfield made similar reference to the subject from a practical standpoint. From my observations, the wave forms are the best upon the lines with the star connection of transformer windings and connected generator neutral, but this connection is possible only when the transformer banks are not operated parallel with others of different characteristics. If such parallel operation were attempted, as has been in some cases, circulating currents between the banks would flow over the neutral, causing heating which should be prevented. It appears to me that the best connection would be a star-connected generator, delta-connected low-tension circuit, and star-connected high tension circuit, with possibly a grounded neutral, the advantages of which were pointed out in the papers presented before the Institute at Pittsfield in May. The wave forms for this connection are good.

We know that an inductive load tends to flatten the higher harmonics and that the wave forms with the inductive load would then be much better than without it. The most serious disturbances would probably occur on an unloaded line, because of the fact that the capacity of the lines exaggerates the higher harmonics in exact proportion to their order in the charging current. If we have, for instance, an eleventh harmonic on the line of say ten per cent it appears in the charging current or capacity current as ten times eleven or 110 per cent, so that upon the line open at the far end we would expect the greater distortion and the most trouble from the higher harmonics. During switching we may have other disturbances due to the fact that the three phases are not closed simultaneously, and as noticed from the experience on the California lines, the less trouble from switching seems to be caused when a grounded neutral with a star-connected high-tension circuit is used.

As to the criterion for judging wave forms: I have not used the American Institute standard because it tells nothing of the order of the harmonics. In analyzing the waves, I have kept a record not only of the effective and maximum values of each wave, but the per cent and order of each harmonic, so that the due weight might be given to the harmonics of higher order. I might say that in these investigations, that none above the fifth was objectionable. I used the connection suggested by Mr. Ferris, that of the condenser in series with resistance for exaggerating the harmonics in the voltage waves. Upon the generator used, the fifth was the only noticeable higher harmonic in the voltage wave. The tests were run throughout without any transmission line connected, so that effect of capacity in the high-tension circuit may be neglected. It was a no-load test throughout.

As to the higher rating of the star-star-connected transformers because of the change in core loss; I think that this rating would be affected very little and would not be the criterion. In the star-star connection the core loss is only a small percentage less than for single-phase. The rating of the transformer would be slightly greater, but on account of the objectionable voltage to neutral, the connection would probably be ruled out in any case.

It is to be regretted that the paper is incomplete in that the author has been unable to deal with the wave forms of three-phase transformers. With three-phase shell-type transformers, the results would be very similar to those obtained with the three single-phase units, but with three-phase core type units, the wave shapes would be considerably changed.

Since the recording of wave-shape was considered to be of prime importance, no special care was taken to calibrate or correct meter readings. Portable instruments of the electrodynamometer type were used for voltage readings. For the measurement of potential upon the high-tension windings a potential transformer was introduced. Care was taken to disconnect all potential reading instruments before taking current oscillograms. While the tests were not made with great scientific accuracy, uniform conditions were maintained throughout, making the results in the different cases comparable.

DISCUSSION ON "SOME OPERATING CONDITIONS OF THE 150,000-VOLT TRANSMISSION SYSTEM OF THE BIG CREEK DEVELOPMENT OF THE PACIFIC LIGHT & POWER CORPORATION," (WOODBURY) SPOKANE, WASH., SEPTEMBER 10, 1914. (SEE PROCEEDINGS FOR SEPTEMBER, 1914).

(Subject to final revision for the Transactions.)

J. Harisberger: There has been considerable discussion as to the necessity of synchronous condensers on this system. I would like to know what actual practise in the operation of the system has brought out; could the system be operated satisfactorily without the use of synchronous condensers?

Mr. Woodbury's paper states that under conditions of short circuit the waterwheel governors shut off water before any appreciable change of speed can take place. I had the impression that the contrary would take place, that the governors would open up the gates.

I would also like to know if there are any transpositions in either of the transmission lines?

J. B. Fisken: One thing that struck me in listening to Mr. Woodbury's paper was the apparent success of the preliminary work. If all the work that Mr. Woodbury has told us of, has developed only the troubles he describes since the line was constructed I think he is entitled to congratulations. I am reminded of an experience we had here eleven years or so ago when we first put into commission the line from Spokane to the Cocur d'Alene mines at 45,000 volts; none of us ever had the experience of seeing a line in operation at 45,000 volts; we didn't know what was going to happen, and inquiries were made as to what we should look out for. We were advised that all we had to do was to patrol the line and if the patrolman heard any insulators making any noise it was a sign they were defective. The noise was described as like the noise of frying steak. We energized the line and every insulator in that line sounded like frying steak, but there was not a single case of trouble; that of course was a comparatively low voltage.

It occurs to me that it might be possible to improve the operating conditions by adjusting the voltage so that for the greater part of the day the synchronous condensers might be cut out. The load factor is high, and I would like Mr. Woodbury to tell us whether it would be a practical operating proposition to cut out the synchronous condensers say from about six o'clock in the morning and until eight o'clock at night. Of course, the only advantage of that is that it is a little less for the substation attendants to look after.

Another point in which I would like to hear some discussion is the method of tying down the conductors to prevent uplift in cold weather. In the line described by Mr. Woodbury, they use two strings, one of which would be in tension in hot weather and the other in tension in cold weather. In our tower line, we have only one short tower line, we use two dead-end insulators for the same purpose and it would be interesting if we could get discussion on that and try to formulate an idea as to which is the better one.

One other thing I would like Mr. Woodbury to tell us about; that is whether they use any resistance or reactance in the ground connections or whether it is a dead ground.

A. A. Miller: I have one question I would like to ask Mr. Woodbury. He mentioned the fact that in the 100-mile section of transmission line an induced potential of 4200 volts exists to ground. How frequently is this 100-mile section grounded when repairs are being made, at one place or more than one place?

M. H. Gerry, Jr.: The achievement of operating a line at 150,000 volts is a most creditable one and indicates in a marked degree the great progress in electrical transmission made in the last twenty years. This is a comparatively short time for the development to take place from potentials around 2000 or 3000 volts up to 150,000 volts or even more. It was my good fortune to be connected with the transmission business during the early days, some seventeen or eighteen years ago. About that time we built a system in Montana and began operating at 50,000 volts. It was then impossible to get a manufacturer in this country to endorse that voltage or unqualifiedly guarantee the transforming apparatus. I remember that we made a compromise by arranging to drop to half voltage if anything serious happened. As a matter of fact, a good many things did happen, but nothing occurred to disprove the general principle that high voltage was desirable and essential for long-distance transmission of power. It is rather an interesting fact that high-voltage transmission was developed in the West; the reason being that it was essential to accomplish the results under the existing conditions, and for the further reason that Western engineers and Western men generally were free from prejudice and were accustomed to undertake problems and seek solutions without regard to what had been already accomplished, provided that there seemed to be no good reason why it could not be done. As I have already said, we constructed in that early day a transmission system between the Missouri River, near Helena, and Butte, a distance of about sixty-five miles, operating at 50,000 volts. This system transmitted a large amount of power and was a success from the start. A few years later the pressure was raised to 70,000 volts, and now in the same vicinity there are lines operating at 100,000 volts and transmitting power up to 150 miles. My experience with all these lines has been most satisfactory. The troubles were few and mainly of a mechanical nature. Of course it took several years to analyze the insulator problem and to determine the necessary conditions in that direction, but to-day there is practically no electrical trouble on transmission lines on the Montana systems. In our part of the country the transmission lines in places reach considerable altitudes, and I would be interested to know the maximum altitude reached on the lines described by Mr. Woodbury.

E. Woodbury. Five thousand feet.

M. H. Gerrry, Jr.: In Montana the lines sometime reach altitudes around 7000 ft. In such high altitudes there is some evidence of loss at the highest voltages, but as it is local it does not affect the general result. Most of the transmission lines in Montana are of wooden pole construction up to about 70,000 volts; at higher pressures the lines are mainly on steel towers. A very large amount of power is handled in this section, the principal transmissions being from points near Helena and Great Falls to Butte and Anaconda. The principal load is in the form of induction motors but there are also a number of synchronous motors used for operating air compressors and direct-current motor-generator sets. Every conceivable kind of load is handled on the Montana system; power, railway, lighting and all kinds of industrial applications to which electrical current can be applied. All the lines and power plants are now in one great system and but little trouble is experienced with regulation or with interruptions of service.

V. H. Greisser: I would like to inquire of Mr. Woodbury whether any extended tests have been made regarding the distribution of potential on the separate units and across the string of units of the insulator, and in general what was found. Also whether any tests have been made regarding the question of what we might perhaps call aging of insulators.

E. Woodbury: Mr. Harisberger and Mr. Fisken and Mr. Fraser have all asked about the same questions, about whether or not the condensers were necessary. I think you will find in the first part of the paper it says that the inherent regulation of the line is from 10 per cent above to 20 per cent below power house potential. I think that the principal excuse for the condensers is the remarkable regulation that they afford us. With the condensers in the receiving station we hold the voltage exactly where it is wanted at all times of the day and night, without any reference to what the power house is doing. When we first started up, the telephone line was not complete and we operated for about thirty days without any telephone line, and we gave very good service. The two condensers are 15,000 kv-a. each, making 30,000 kv-a. of leading component, which is required a good part of the day. Now, that would have to be supplied elsewhere or else the power house voltage would have to be raised to about 175,000, which would be approaching the limits of corona loss.

The matter of using steam turbines for condensers is quite feasible, as Mr. Fraser mentions, but with us we have the vertical type and of course it is out of the question to separate the generator from the turbine.

We are also informed that we should not run the turbines without having steam on them, so there is some expense to produce enough steam to keep them in operation even though they are carrying wattless current.

Mr. Fisken's question about not running the condensers from

6 a.m. to 8 p.m.—Now, that is the time we need them the most. This curve in Fig. 3 only shows the kilovolt-amperes of one condenser in that at that particular time the other condenser was shut down and turbines in the steam plant were supplying 15,000 kv-a. wattless component, so that you can see that from about 7a.m. the condenser is up to almost 1300 amperes, which is 15,000 kv-a. and it runs right through with a drop at the noon hour; otherwise if we did not have the condensers the power house voltage would go up to 175,000 or so with the constant difficulties in regulation.

Mr. Miller's point about the line 100 miles or so long having 4200 volts induced potential—before we ground either end of that 100-mile section, we make a static voltmeter test to get the true potential, and find it 4200 volts, and when we ground the other end, it drops to about 500, and then we put another ground at this end. Also the linemen all have positive instructions to put their ground on before doing any work.

In regard to Mr. Greisser's question concerning the stress on the different units, we have never made any tests on that, but there were some made at the time the insulators were being manufactured when they were tested for flash-over, etc., and I don't know just what means they had of determining what the stresses were, but we got the report that the stresses were very uniformly divided, which does not seem to agree with some articles I have read and papers presented before the Institute. Of course, as to the aging of insulators, we have not been operating long enough to know about that, we have been operating only about ten months. As to the mechanical stress, they will stand about 10,000 pounds and we use two strings in parallel, so that the stress is divided, about half of the stress is on each string, and normally there will only be about 5000 pounds altogether, only about 2500 on each string, but they will go as high as 8000 or 10,000 lb., so that would be 4000 or 5000 on each string. Long spans of course are strung the same as the short ones, all pulled up with the dynamometer to the same tension.

DISCUSSION ON "ELECTRIFICATION OF THE BUTTE, ANACONDA AND PACIFIC RAILWAY" (COX), SPOKANE, WASH., SEPTEMBER 10, 1914. (SEE PROCEEDINGS FOR NOVEMBER, 1914.)

(*Subject to final revision for the Transactions.*)

Paul Lebenbaum: This paper looms up as an oasis of facts in a desert of glittering generalities, and records a distinct step forward and upward in heavy railway electrification. It is unique in that it sets forth, not only facts, but actual figures on operating results, for a road that made the change from steam to electricity solely in order to obtain increased capacity and greater economy in operation. Most, if not all, of the heavy electrification has been done for the purpose of overcoming an operating condition for which steam was unsuited, such as the New York terminal electrifications, the work of the Great Northern at the Cascade Tunnel, etc. It must therefore be peculiarly gratifying to the management and its engineers that the economies resulting from the change were so quickly and positively established.

It would, no doubt, take some time to properly correlate and digest the many figures that Mr. Cox has presented; what little I have to contribute to the discussion will therefore be in the nature of a comparison with some of the results obtained on the Portland, Eugene & Eastern Railway, operating at 1500 volts over some 105 miles of single track road, exclusive of sidings. All passenger movements are electric, freight being still handled by steam, the speeds in passenger service exceeding 50 miles per hour.

It appears that 90 per cent of the B. A. & P. train mileage is made in freight service at the comparatively low speed of 16 to 17 miles per hour, while all of our passenger service is at much higher speeds. Both roads use the US-122-E. type of pantograph, having a five-inch diameter roller, as a current collector, the B. A. & P.'s problem being to pick up large currents at low speeds and the P. E. & E.'s smaller currents at high speeds.

We make approximately 45,000 train miles, or 120,000 motor car miles, per month. Each motor car uses its pantograph, there being no power bus on our equipments. I was therefore interested in Mr. Cox's statement as to the average life of collectors being 10,000 to 12,000 miles. We have also found it necessary to equip our collectors with a roller type of bearing, discarding the graphite bushings originally furnished. Since that time we have made well over 20,000 miles each on enough collectors to convince us that 50,000 miles should be the average collector life under our conditions, where each motor car takes from 100 to 150 amperes. It no doubt is reasonable to assume that the smaller mileage made by the B. A. & P. rollers is in part due to the heavier currents they must collect; although the lower speeds made by 90 per cent of their rollers should, to my mind, somewhat offset this latter condition.

The whole subject of current collection, in small or large quantities at high or low speeds respectively, presents a very interesting problem, the solution for which, at least in this country, is yet to be found.

I noted that equipment trouble on the 2400-volt locomotives was negligible. We have also had practical freedom from serious troubles; in one or two instances arcs from the circuit breakers have jumped to ground, due entirely to the method of venting the gases engendered by the breaking of the current. I ask Mr. Cox whether the B. A. & P. has had any similar experiences in the breaking of high-voltage arcs.

C. P. Kahler: I note that a comparison has been made between the electric and steam operation costs of the Butte, Anaconda & Pacific Railroad, and that a 20 per cent earning on the investment for electrification is shown, based on the first six months' records of the operating expenses. I would hardly think that a comparison based on six months' records would give a correct idea of the relative costs of electric and steam operation of this railroad. For instance, take the item of locomotive repair costs, which are usually divided into two parts, light running repairs and shop or heavy repairs. Six months' service with electric locomotives would give very little, if anything, on the shop or heavy locomotive repairs, and consequently I would judge that the electric locomotive repair expense for the first six months would necessarily be considerably less than will be the case after the locomotives have been in operation several years and sent through the shops once or twice. I have noticed that the repair costs of steam locomotives usually start out at a very low figure per locomotive-mile, and gradually increase, as the locomotive gets older, until the cost per locomotive-mile will quite often reach several times the cost when the locomotive first began operating. Consequently I would hardly think it proper or fair to the steam locomotive operation to compare the first six months' expenses of the new electric locomotive operation against the cost of maintaining a few old steam locomotives.

The steam locomotives used in operating the Butte, Anaconda & Pacific were not very large when compared with the size of the steam locomotives used on many other railroads, and it would be interesting to know what saving would have been made by replacing the old steam locomotives of the B. A. & P. with new and larger steam locomotives, and also what would be the saving by electric operation as compared with steam operation, using large steam locomotives.

For some time past I have been of the opinion that the greatest saving which would result from electric operation of steam railroads would be from the reduction in the steam train service, and the data given in Mr. Cox's paper tend to confirm this opinion, for by electric operation three crews are now hauling the same tonnage as four crews did with steam locomotives, a reduction of about 25 per cent in the train service. As the train crew expense on most roads is usually somewhat near

20 per cent of the total operating cost of the railroad, a reduction of 25 per cent in this expense by electric operation would mean that the total expense of steam operation would be reduced about 5 per cent on account of the reduction in train service alone. Additional saving would, of course, be made on account of the lower cost of locomotive repairs, less engine house expense, and other detailed costs which would result by electric operation.

I note that electric locomotives with four axles, having a combined weight of 80 tons, are used on the B. A. & P. R. R., and that two of these four-axle units are rated as one locomotive of 160 tons. I judge that units of this weight were selected in order to allow one pantagraph per unit for collecting current. However, it would appear to me better, in determining the weight of an electric locomotive, to work from the other end. In other words, to determine the maximum weight which your track would support, and make the axle loads of the electric locomotive correspond to this. For instance, the Union Pacific system allows a maximum weight on locomotive drivers of 55,000 pounds, which would make a four-unit locomotive, similar to the B. A. & P. electric locomotives, weigh 110 tons on the drivers, a fairly large size locomotive. The Pennsylvania, I believe, allows as high as 65,000 pounds on each driver, which would make the total weight of a four-driving-axle locomotive equal to 130 tons on the drivers. This would be nearer my idea of a locomotive which would be best fitted for the freight service. This would also make the use of the tractor auxilary referred to unnecessary.

In conclusion, I would say that while I do not consider the results as absolutely conclusive, the paper is very valuable in that it bears out many claims made as to the advantages and lower economy which would result from electrically operating steam railroads. Further, the fact that the B. A. & P. R. R. is simply a short line would not be an especially favorable condition for expenditures in electric traction work, and the favorable showing which is evidenced by the data given in Mr. Cox's paper would probably be very much better if applied to an engine district of about 150 miles in length, and under such conditions I believe that the earnings which would be made on the investment for electrification work would in many cases exceed the 20 per cent which Mr. Cox claims as the earnings on the investment from the electric traction work of the Butte, Anaconda & Pacific Railroad.

J. C. Ralston: The author designates the engineman, the man who drives the locomotive, as a locomotive engineer, and again he speaks of him specifically as an engineer, I think. Now, 90 per cent of engineers are responsible for an incorrect use of that word. I feel this: that if the four premier engineering societies, namely, the electrical, civil, mechanical, and mining, would all take up this question and use the proper word, we would not be confused as we are by reading in the papers of the hoisting engineers' society and the various societies in domestic lines. I hope that the engineers themselves will follow the correct terminology and then the public will later follow our lead.

A. A. Miller: I ask Mr. Cox to give us a little more description of those tractors; do they have cabs?

W. K. Stacy: I wish to inquire regarding the life of the trolley wire when using the roller collector. I have had experience with the sliding collector and under certain conditions the wear on the trolley wire was excessive. This was particularly apparent with rigid hangers at the ends of line circuit breakers. What style of trolley wire suspension is used on the B., A. & P?

Paul Lebenbaum: After the line had been in operation for about five months, the trolley wire was carefully calipered to determine whether there had been any wear, especially at what might be called hard spots in the line. No measurement taken showed a variation from the true diameter of the wire greater than the 2 per cent variation allowed the manufacturer under our specifications.

J. B. Cox: Referring to the remarks relative to the steel rollers used for the collection of current on the pantographs, these collect 600 amperes at from 16 to 20 mi. per hr. quite satisfactorily. It would be rather difficult to compare the life of the rollers used on the Butte, Anaconda & Pacific locomotives with similar rollers on ordinary interurban cars where they are required to collect a much smaller current and at somewhat higher speeds. The heavier currents required in the operation of the locomotives would undoubtedly account for the much shorter life in this case. The 10,000 to 12,000 miles being obtained from the rollers on the locomotives is equally as great as was expected of them when it was decided to install this type of collector.

As compared with the slider type of collector, the roller is considerably heavier and somewhat more complicated, but on account of its longer life and less wear on the trolley wire in the heavier class of service it has been considered more desirable for the collection of heavy currents. It is generally admitted that the slider is more simple and if it can be perfected so as to collect an equal amount of current with even half the life in mileage obtained from the roller and with equal wear on the trolley it will usually be preferable and would no doubt prove more economical both as regards first cost and maintenance. Considerable progress is being made in the development of a sliding pantograph in the above respects and I am of the opinion that their use will become more general. I have recently seen up to 3000 amperes collected without sparking by a single pantograph with a double sliding collector. This was on the occasion of test running, which gave most promising indications of practical success, but actual service under general operating conditions will be necessary to perfect these sliders in every detail. Personally, I have no doubt but that either type of collector can be made to operate quite successfully under almost any practical conditions.

As to the number of linemen employed in the maintenance of the distributing system, I have given the exact number regularly retained on the pay rolls of the company. The amount stated as being the cost of maintenance of the distributing system was based on the rate of the monthly charges for the six months for which the operating costs are given and cover all items chargeable to this account, which are principally for material, labor and work-train service. These costs are at the rate of approximately **$125.00** per mile per year and are about what is expected to be average costs for at least the normal life of the wooden poles, which is expected to average in this locality from twelve to fifteen years.

In reference to the wear on the trolley wire, this is so small to date that any statement as to actual measurements would be of small value since the allowable variation in the diameter of the new wire might easily make such figures misleading unless careful measurements had been made and recorded before the electrical service was started. This wear will usually be noticeable first at hard spots in the line where there are pull-offs or rigid hangers. The construction of this line was designed with a special view to flexibility, so as to facilitate the operation of the roller collector as well as to reduce the wear on the trolley, and undoubtedly it is the most flexible construction of the kind in this country at the present time.

Relative to the suggestion that the first six months of electrical operation is too short a time on which to base definite comparisons, I have not stated that such is to be done, but I have given actual figures from official records accompanied by an explanation of the principal conditions under which the results were obtained.

The last six months' full steam operation has been compared with the first six months' full electrical operation and it just so happens that the changing-over period lasted six months, making the comparison for the same months of consecutive years. The systems of accounts were kept identical so that results would be directly comparable; the same men have taken care of the maintenance and done the operating in each case and very much in the regular way, making only such changes as were naturally suggested from the use of the new motive power, and the entire change has been made so gradually that I doubt very much if there has heretofore been such favorable opportuni for obtaining operating costs where so direct a comparison between steam and electric locomotives could be made.

In the first place the conditions for segregating the costs have seldom been so favorable, and secondly, operating companies that would give out such full information have been exceptional.

Precisely the same conditions might not be met on another road, hence exactly similar results would not be expected. The extent of the usefulness of these figures in forecasting results of proposed electrifications depends upon our ability to properly adjust them to apply to any other particular case. It has been suggested that the cost of repairs to the electric locomotive for the period considered is less than it will be in the future and that for this reason the comparison of these items might not be representative, it being unfair to compare the cost of repairs of new electric locomotives with that of steam locomotives which have been in service a number of years. While this is not an unnatural inference, in practice I have not usually found it to be true and in this particular instance I feel confident that the cost of maintenance of the electric locomotives given in Table VI, which includes the charge for depreciation, will be less in the future than it has averaged for the six months in question. The reasons on which this expectation is based are, first; that of the total cost per locomotive mile amounting to 7.47 cents, 2.46 cents is for depreciation, leaving 5.01 cents as the cost per mile for actual repairs as the term is generally applied. This is fairly high under ordinary conditions but not unreasonably so here under the special circumstances as it included the cost of considerable experimenting with pantograph rollers and minor improvements to the equipment in adapting them to the special conditions required by the service; so that on the whole about as much work has been done on the locomotives during these six months as will be averaged at any time in the future and the decrease in the rate of depreciation on the basis that it is being determined will more than take care of any probable increase in actual repairs.

Secondly; the old steam organization was retained as far as required for the maintenance of the electrical equipment. It would be unreasonable to expect that they will not improve in efficiency as they become more familiar with the new equipments, and the shop facilities will be gradually improved also resulting in reducing the cost of repairs on the electric locomotives.

Taking all these circumstances, with which I am familiar, into consideration, I shall be very much disappointed if the cost of maintenance of the electric locomotives per mile operated does not show a gradual decrease during the next few years. I have had considerable experience in connection with the initial operation of electric locomotives and their maintenance during the first two or three years in service, and this experience has led me to the conclusion that the cost of maintenance of an entirely new type of equipment in the hands of an old steam organization will usually be equally as high the first year as the average cost for a number of years after. This is particularly the case where dual equipment is operated and where the costs of minor developments and adaptations are taken care of and charged to the maintenance department. When utilizing the old organization under such conditions it is a mistake not to begin a regular system of general inspection and repairs at the very beginning so as to get the men as familar with the new apparatus as possible so that when these repairs are actually necessary they will not only have a definite idea of the work ahead of them but will also be provided with the necessary tools so that they can do the work with the same efficiency as in the case of the steam locomotives. On the whole I have found it more easy to break in old steam organizations to operate and take care of electric locomotives than to adapt electrical men to the work who had not had previous steam railway experience.

It might be of interest to state here that at the end of a year's service a general shop inspection and overhaul of the electrical locomotive was begun with this object in view. The trucks were taken out from under the cab, the motors taken off, the armatures taken out and every thing gone over as thoroughly as possible, including the turning of tires and rebabbitting of armature bearings.

This was done corresponding to similar annual general overhaul of a steam locomotive. The electric locomotive was in the shop one week whereas four weeks were required on an average for the steam locomotives for a similar overhaul and the costs in each case were about proportional to the time the locomotives were in the shops; that is, the electric locomotive cost was about one-quarter that of its steam predecessor. The tires on the drivers of the electric locomotive will average somewhat more than double the mileage between turnings obtained from those under the steam locomotive.

The many sharp curves on the entire system result in rapid wear of the flanges.

While I have had little actual experience in connection with the maintenance of new steam locomotives, I have often had occasion to investigate the costs of repairs to steam locomotives. My impression is that on the first installation of a new type of steam locomotive on any road the adaptation and development charges during the first year are apt to make up for the smaller number of general repairs that are required during the first year, much the same as in the case of the electric locomotives. As an instance I will cite the case of a number of large Mallet engines, the cost of repairs for which was 20.46 cents per mile for the first six months, whereas the average cost during the first four years of their service was 23.34 cents. The cost for the second year was greatest while those for the third year were least. I do not believe this is exceptional. In the case of electric locomotives I have in mind a record in which the cost of repairs the first year was 6.7 cents per locomotive mile and for the fifth year 4.1 cent, the average for the five years being 4.85 cents; and another where the cost for the first six months was 5.45 cents per mile and the average cost for the fourth year was 4.98 cents. Both these instances were steam road electrifications with new 600-volt equipment. As a matter of fact most of the records I have seen are of a similar nature, and it is these facts coupled with actual experience that are responsible for my opinion on the subject.

It would be only natural to expect that the cost of maintenance on steam locomotive, during the last six months they were expected to be used, before being replaced by electric locomotives, would be somewhat neglected and hence the costs per locomotive mile would be less than the average. However, I investigated the records over a considerable period of steam operation and found no very great variation on account of this but that the figures for the six months quoted were fairly representative.

In this connection it may be stated that the Butte, Anaconda & Pacific Railway has always kept its locomotives in an unusually good state of repair and that the prices paid for all classes of labor are perhaps higher than is paid anywhere else in this country. The fact that the cost of labor is high is not altogether favorable to the electrification inasmuch as it greatly increased the first cost, but insofar as the operation of transportation and maintenance of locomotive is concerned, it is more favorable since the number of employees are generally reduced to some extent and the overtime is apt to be considerably less.

Referring to the suggestion that the electric locomotive units should have been larger, this subject was very carefully considered before the design of the locomotive was begun and after an investigation of all the conditions and the general requirements of the work it was agreed that a unit approximating 80 tons on the drivers would give best general results and that no advantage offered by a heavier unit for any part of the service would offset the disadvantages of a mixed type of equipment. Electric units weighing 100 tons are quite common, and the three-phase electric units which have now been in operation on the Great Northern Railway for five years weigh 115 tons each, all of which is on four axles, so that ordinarily there should be no difficulty in providing as heavy a unit as conditions might require. In the case of a mountain division on a transcontinental line it is usually desirable to use as heavy units as the draft gear of the rolling stock will permit. In the case of the B., A. & P. Railway the conditions were not considered generally favorable for the use of larger units. Longer trains than could be handled by a double 80 ton unit locomotive would have required the lengthening of yards, sidings and passing tracks. Heavier units in this case would also have increased the peak loads on the substations and lowered the load factor. The draft gear on the ore cars and many other local conditions had to be considered in this connection, the general result of which led to the adoption of the present unit.

Referring to the burning out of contactors, due to dust or irregularity in following the proper sequence of operation, there have been no instances of serious trouble with contactors, from any causes so far as I am aware. There have been instances of flashing over of insulators at the back of the contactors which was thought to have been due to the accumulation of dust from the ore, which contains some copper. There is, naturally, a great deal of such dust and the blowers located in the cabs of the locomotive cause more of it to be drawn over the apparatus than would be done otherwise. We had really expected much more trouble from this source than actually occurred. These arc-overs did not result in any serious damage. It was only on inspection that it was found the insulators had arced over, as apparently the arcing had occurred when the contactors were opening the circuit so that the current was shut off before the arc did any thing more than burn off the dust, after which there was no further bother.

In one or two instances where the main trolley contactors were involved, the main fuse was blown but as far as I am aware no contactors have been damaged so as to cause any delay or to require immediate attention. In this particular control equipment the transition between series and parallel connections, where troubles from improper sequence of coming in and out of contactors are most likely to occur, the contactors involved in the transfer are operated by means of a cam which insures a proper and uniform sequence and no troubles whatever have been experienced from this source.

During the first ten months of operation no contact tips had been changed on any of the contactors nor had any repairs to same been necessary. On the whole the contactors on the locomotives show less signs of arcing or burning than on an ordinary 600-volt locomotive in a similar service.

The commutators of the main motors are in such splendid condition that during the visit of some German engineers to inspect the electrification about six months after the locomotives had been in operation, it was difficult to convince them that the commutators had not recently been turned.

Relative to the term "engineers" as used when referring to the drivers of the electric locomotives, it is in accord with steam road practise, as has been the intention all through. Steam operators will be equally interested with the electrical man in the results and the terms used and comparisons made throughout are meant to be equally clear to both.

Table VI is made up to conform to the usual steam railway locomotive performance sheets and practically the same form was retained for the electric locomotives in order that the comparisons relative to the performance of each might be as direct as possible.

The passenger locomotive miles and the passenger train miles on the Butte, Anaconda & Pacific Railway are the same, as only a single unit is used to haul the passenger trains.

Referring to Table VI, it will be seen that the electric locomotive miles made in passenger service for the six months considered were 43,170, which is approximately 12.5 per cent of the total miles operated by all electric locomotives for the period.

The tractor trucks which are to be supplied with the new locomotives on order for the spotting and switching service will be arranged for coupling onto a standard locomotive unit much as an extra motor car is added to a multiple unit train, except that the electrical connections between the unit and the truck will be such as to connect the motors mounted on the latter in series with those on the former instead of in multiple as in the case of the extra car in a multiple unit train.

In other words, it will form a three-truck locomotive with six motors, arranged for all six to be operated in series on the usual series points of the controller and with a series multiple connection consisting of two circuits of three motors each on the usual parallel points.

This plan was considered preferable to adopting a special three-truck locomotive since when the extra truck is detached the unit is interchangeable with all others, or any of the existing units can be arranged for operation with the extra truck by the provision for the necessary electrical connectors.

DISCUSSION ON "APPLICATION OF ELECTRIC MOTORS TO GOLD DREDGES" (ROSENBLATT), SPOKANE, WASH., SEPTEMBER 11, 1914. (SEE PROCEEDINGS FOR AUGUST, 1914).

(Subject to final revision for the Transactions.)

Ford W. Harris: The problems so clearly defined by Mr. Rosenblatt are, in general, those that confront any engineer proposing to equip rough heavy duty machinery with motors. As electrical engineers we are in duty bound to give electric power the benefit of every doubt when the expediency of a given installation is considered but that the application of motors to dredges, shovels, and the like, is a hard problem must be understood at the outset. It is primarily a problem of applying a constant speed, constant maximum torque motor, to be a variable speed, variable torque load. More particularly it is the application of a constant torque driving means to a variable torque load. We have the problem of a widely variable load that must be economically handled regardless of the speed. The operator wishes to operate the major portion of the time at constant speed with a fairly uniform load. At times this load is enormously increased and at times he desires to greatly reduce the speed for repairs, etc. In general as far as satisfactory operation is concerned the enormous pulls occasionally needed may be and preferably should be exerted at a low speed so that the actual power requirements may be fairly constant.

Obviously what is needed is means for connecting the load and the motor is variable speed ratio, the problem being very similar to that solved by the change gears of an automobile. Obviously also no such mechanical means has been devised which will handle the very variable shocks and strains incident to transmitting 500 h.p. to such a load.

The method by which Mr. Rosenblatt has solved the dredging problem is open to certain very obvious objections. Speed control by liquid rheostats involves at the outset large energy losses, the rheostat being primarily designed for such large losses. Motors having the mechanical and electrical characteristics outlined are expensive and heavy. It should be remembered that when a wound rotor motor has its speed reduced by the insertion of external resistance there is no increase of torque but merely a decrease of speed. The power output of the motor is reduced with the speed. This is only a partial solution of the problem.

I have personally figured many installations of large and small motors to hoists, shovels, and the like, and I believe that a serious mistake is made in applying a-c. motors to work of this kind. Particularly I think that the application of the a-c. motors of any kind to digging service on a dredge is poor engineering. Here you need a moderate torque at a high speed and a much larger torque at a correspondingly reduced speed. The larger companies have made many installations of a-c. motors for such service and made them stick, but it is significant that most large mine hoists are operated by d-c. motors, through the Illgner system, and that our street cars still run largely with d-c. motors in spite of persistent efforts to enlarge the number of single-phase installations. It is further to be noted that the single-phase railway motor has series motor characteristics, and that few installations of induction-motor-driven railways have ever been seriously attempted in this country. If it is not feasible to operate a railway car, which is an approximately constant load at variable speed, with induction motors how much more hopeless it is to operate a gold digger which requires large torques at times when the speed may be reduced to keep the power input fairly constant.

To my mind there is no good way to drive such a load from a constant-torque motor. The load is one that requires series motor characteristics. If there were available single-phase series motors which could be bought at a reasonable price and maintained at a reasonable cost they might be used in this connection. Barring such motors the proper system would be the application of a double or quadruple equipment of series d-c. motors in combination with a d-c. generator—a-c. motor set.

With such a multiple motor drive and proper series parallel control it would be possible to operate on a variable torque basis and get fine results, the motors running four in mutiple under normal conditions and being thrown in series for heavy pull-outs at low speeds. The power economy would be high and with proper cutouts on each motor the reliability factor would be increased, as three motors could be used to operate in an emergency. While the first cost of the motor equipment would be high, the greater flexibility and reliability of the equipment would result in greater output at the dredge which would soon wipe out the additional investment.

M. H. Gerry, Jr.: I am glad to say a word on this paper because there is much of interest in connection with such a machine as a gold dredge. This paper is a further demonstration of the great flexibility of electrical power and the wide diversity of its application. I disagree with the statement made by some one in the discussion, that there is any difficult principle involved in this application of electrical power. The problem is to ascertain in advance, the actual conditions of operation, and in this respect it does not differ from electrical traction or the thousand and one other applications by electrical power. Once these conditions are fully understood, the difficulties very largely disappear and are then only those quite commonly met with in solving mechanical and electrical engineering problems. However, it requires much study and time to analyze a problem of this kind, and it is here that the skill of the engineer is required.

It has been my good fortune to have some connection, in an engineering way, with the dredges which form the subject of Mr. Rosenblatt's paper. I was familiar with the situation from the first, when the dredges, then in operation, were driven by steam engines. These older dredges have all been rebuilt and are now operated by electrical power, but the dredge which forms the special subject of Mr. Rosenblatt's paper, is a later installation and was designed originally for electrical operation. The problem at first presented was that of the general advisability of applying elecrical power to the operation of dredges in this situation, and it was a question on which engineers differed. The ground was hard, there were many large boulders and the bedrock was at great depth. The steam dredges were experiencing much difficulty, and the power was insufficient for the work and there were constant breakdowns and delays. A very able engineer who was called into consultation, was of the opinion that the conditions were altogether too difficult to permit of operation by electrical motors. The ever-varying pull on the digging chain, the frequent obstructions met with in the way of boulders and other causes, tended to produce enormous strains and varying torque on the driving motor, and render questionable the successful operation by electrical power. Those who have seen a dredge of this kind operating in hard ground will appreciate how difficult the problem appeared at that time. One engineer observing the operations, used this expression, " see it toil, see it toil;" the inference being that the " toil " was altogether too strenuous to be undertaken by an electrical drive. That, however, is now all history, and we know that for any dredging service, no matter how difficult, electrical motors properly designed are altogether suitable. The dredge is a comparatively simple machine; as here applied it is a combination of elevator and excavator. At times there is very little actual digging, as the earth is loose and falls into the buckets. Under these conditions it is merely a question of elevating this earth to the surface. As the excavation reaches bedrock the conditions change; the material is hard and tough and must be torn apart with the expenditure of a considerable amount of energy. From my knowledge of conditions at 'Ruby and elsewhere, I would say that the dredge operations for the machine described by Mr. Rosenblatt, are the most difficult in this country. This hard digging, the great size of the dredge and the depth from which the material was excavated, were the conditions surrounding the problem for this particular dredge. The bucket chain is a massive affair and it moves at a slow rate of speed. The pull on the bucket chain is constantly varying, due to the ever changing conditions of digging, and also to the further fact that the chain is driven from the top by a five sided tumbler, resulting in a constantly varying driving radius. The motor torque is, therefore, ever changing and may vary widely during short intervals of time.

One ofthe important conditions of dredge operations is to maintain maximum speed of the digging chain the the upper part of the excavation and to be in readiness to develop maximum pull on the chain, at somewhat lower speed, as soon as bedrock is reached and the difficult ground encountered. It follows, therefore, that a considerable measure of speed control is absolutely necessary for successful operation in this situation. Many methods of obtaining this speed control have been suggested and applied, but the one described by Mr. Rosenblatt has proven eminently successful for conditions met in actual service. Some engineers have suggested a change to a direct-current drive, but I have never been able to obtain any better efficiency or improved performance for direct current, where the available source of power was alternating current, and the necessity existed, therefore, of using conversion apparatus. At the present time there is nothing better or more available for this service than an alternating-current motor having a wound secondary with a control rheostat capable of continuous operation.

Mr. Rosenblatt has well said that for the best results it is necessary to keep these dredges in as continuous operation as possible. When the records show that month in and month out the dredges have been in service 80 per cent of the total time, it is certainly a creditable performance. Such results as this that prove that electrical power, when applied to dredge operations, is a great success, and that the apparatus as described by Mr. Rosenblatt has materially contributed to this result.

Some discussion has arisen in reference to the relative merits of a belt drive as compared with a direct gear drive for the main bucket chain of a dredge. This is a question more of expediency and economy than of performance. It is not well to make the drive too rigid, and some means of providing for a little slip in case the buckets come up against a rigid obstruction, is very desirable. With a small or moderate size dredge, this result can be obtained in a rather inexpensive way by using a belt drive from the motor and permitting the belt to slip if occasion should arise. On very large dredges, however, belts are too bulky and are very objectionable for mechanical reasons, and it is better to provide a gear drive with a form of mechanical slipping friction introduced at some point between the motor and the bucket chain. This slipping friction should be designed, not as an ordinary friction clutch, but as an actual slipping friction.

To return to the matter of control for the main digging motor and referring especially to the liquid rheostat described by Mr. Rosenblatt, I would like to add that this has proven to be a most satisfactory piece of apparatus. For hours at a time the motor is operated at reduced speed and the heat developed in the rheostat is taken care of very nicely by the cooling coils. The regulation is excellent and the man operating the dredge has fine control over the bucket chain. For motors on small dredges, almost any kind of rheostat will work well, but for such an immense dredge as the one here described, I know of no better arrangement than the liquid rheostat. The arrangement whereby the cooling coils are placed on outside of the boat in the dredge pond, is worthy of special attention. This device has obviated all the trouble with the circulation of muddy water through cooling coils immersed in the rheostat tank, and is one of the reasons for the success of this installation.

In conclusion I would like to emphasize the thought which I first mentioned; that it is not at all difficult to apply electrical power or electrical methods to the operation of any machinery if the conditions be carefully analyzed in advance, and the proper use be made of methods and machinery now well understood.

F. A. Ross: I am conscious that a mining engineer can take but small part in this discussion of Mr. Rosenblatt's paper. The word "mining" can scarcely be applied to gold-dredging since, as Mr. Gerry has said, dredging is but the elevation of gold-bearing gravels and a transfer of the same to another point; therefore, the design and operation of dredges comes within the province of the mechanical, electrical and, often, the hydraulic engineer rather than in that of the mining and metallurgical engineer. The latter is called into the question only at the beginning and at the end. Because of his training in estimating the value of mineral-bearing ground he does the drilling or sinks the test-pits and then he estimates the profits possible, or probable, from a handling of the greatest tonnage practicable. At this point he must turn for help to the mechanical engineering departments of the dredge-builders, where the data he submits govern the design of the dredge; and the mechanical engineer, himself, must apply to the electrical engineer for motor designs and for advice as to the general application of electricity to the needs of the case in hand. But the mining engineer must make no mistake as to the average character of the gravel to be worked nor may he fail to note the heaviest duty that the dredge must perform. Moreover, as a metallurgist he must specify the type of gold-saving apparatus to be used but, once the machine is built and at work, he may safely step aside and leave its operation to the skilled dredge-crew and takes orders henceforth from the mechanical and electrical engineers. Electricity has so far superseded steam as a motive power in dredging that there are few steam dredges employed today in working gold-bearing gravels.

As Mr. Gerry said, the latest gold-dredges are mechanical monsters, performing feats of strength and endurance that are almost unbelievable by those that see them for the first time; and they call for a refinement of theory and practise both in mechanical and in electrical design. The close-connected buckets must tear away at consolidated beds of boulder-gravel without pausing and must work out of sight, under water, at depths of 70 feet or more. Gravels differ greatly in character, some being composed of small, nearly uniform, boulders, while others contain boulders of all sizes, even up to a size that renders dredging impossible.

The greatest difficulty, then, lies not so much in the building of a machine strong enough to stand up to the duty imposed upon it as in an accurate determination of the total work to be done and the character of that work. Mr. Rosenblatt mentions a maximum capacity of about 250,000 cu. yd. per month for the largest gold dredges, but there is one up in Idaho Basin which, according to the statement of its general manager, made a record of 340,000 cu. yd. in one exceptionally good month. In this case, the gravel is small and uniform and the beds shallow.

L. K. Armstrong: After what Mr. Ross has said I don't think it will be necessary for me to say anything or to apologize for the little the mining engineer knows about gold dredges.

I have in mind the early days when the electrical engineer was seeking a market for his current. Some of them conceived that they might apply it to the gold dredge business, and after a considerable time and many attempts they seem finally to have acquainted themselves so thoroughly with the business that the business has been practically turned over to them.

I was trying to think, while one of the speakers was talking, about a meeting of the American Institute of Mining Engineers, when this particular subject was brought up and there was a lot of discussion on the question of whether or not electricity could ever be applied successfully to the operation of a gold dredge; the discussion was all in favor of the negative. Today from the information we have here, I find that gold dredging would be practically unsuccessful, and I am very certain that is so in many cases, but for the application and practical developments on the part of electric engineers and the application of electrical power.

W. M. Shepard: In regard to the case of squirrel-cage vs. slip-ring motors for screen and stacker drive. All of the earlier California dredges were equipped with squirrel-cage motors and it is only on the larger dredges built in the last few years that slip-ring motors have been used.

On large dredges the screen represents quite a heavy starting load, especially if it is started when full of wet clay and rocks which very often happens. The screen is operated continuously when the dredge is in operation so that the characteristics desired are good efficiency and high starting torque.

On large dredges for deep digging, the stacker is very long and elevates the material to a considerable height; this is necessary to get the large amount of material handled out of the way. On the Yuba Consolidated Goldfields Dredge No. 14, which digs to a depth of 70 ft. below the water line, the stacker is 137 ft. long. Starting a stacker of this kind, especially if it happens to be loaded as is frequently the case, requires a high starting torque and it sometimes takes several minutes to bring it up to speed.

If a stacker of this kind was operated by a squirrel cage motor of ordinary design it would require a larger motor than if the slip-ring type was used on account of the lower starting torque.

A squirrel-cage motor with high-resistance rotor could be used which would give the required starting torque, but at the sacrifice of efficiency, and as these motors are large size, those on some of the larger dredges being 75 h.p., and operate at all times that the dredge is running, this loss in power even at a low rate would become quite an item. With some dredges where a considerable number of small boulders are handled over the stacker, the speed has to be reduced at times when a number of these are being handled, as, if the speed is too high, the boulders will not stick to the stacker belt and be carried over the top, but will roll down and cause considerable trouble. A slip-ring motor with proper resistance would take care of a case of this kind when a squirrel-cage motor would prove unsatisfactory.

The difference in maintenance cost between the slip-ring and the squirrel-cage motors used on these drives is shown on actual operation to be negligible; for the slip-ring motors occasional extra brushes are required and for the squirrel cage extra contacts for the starters.

The drum-type controllers used with these motors give practically no trouble as the service required of them is comparatively light.

Regarding Mr. Rosenblatt's recommendations covering specifications for the digging motor: it seems to me that the introduction of the special features which he recommends are confusing and not to the advantage of the purchaser. For instance, a motor designed to meet the standard heating guarantees adopted by all American motor manufacturers from the A. I. E. E. Rules would, in all probability, meet the specifications submitted by Mr. Rosenblatt and the use of standard specifications would be of advantage to both the purchaser and manufacturer. Furthermore, it is not usually necessary for the digging motor to run for considerable periods at reduced speeds. The rate of digging can be controlled either by changing the speed of the bucket line (varying the speed of the digging motor) or by varying the rate of feed, which is controlled by the swing winch.

The dredge has side lines on either side connected to deadmen on the bank. The swing winch in connection with these lines swings the dredge back and forth across the face of the cut while the bucket line is in operation. The rate at which the dredge is swinging governs the feed of the buckets and so the amount of material moved and the load on the digging motor.

It is much more efficient to allow the digging motor to operate at full speed with all resistance cut out of the secondary and control the load by means of the swing winch motor (which is from 10 per cent to 15 per cent of the capacity of the digging motor) than to operate the digging motor at reduced speed with consequent losses in the secondary resistance.

In regard to special bearings in the digging motor to resist upward thrusts, the large majority of gold dredges have the digging motors belted, which requires no special features in the bearings. The larger motors are usually provided with three bearings.

Regarding those motors which are geared: the bearing thrust when digging should be downward; the only times when the bearing thrust should be upward would be when the bucket line was being backed up which would be only a very small fraction of the time it was going ahead and when it was being backed up the load would be light as there would be no digging.

The point which I wish to bring out is that standard equipment, if properly applied is well adapted to meet all conditions of dredge service. I had had to do with the electrical equipment of something over thirty gold dredges of bucket capacities ranging from 3 to 18.2 cu. ft. and digging depths of from 15 to 70 feet. These dredges operate in every character of ground and all use standard equipment. Among them are some of the most successful dredges yet constructed. The problem in electric drive is in proper application and not special equipment.

Regarding the control of the digging motor, I believe that proper drum-type controllers are all that is required for motors up to 200 h.p. capacity. There are quite a number of digging motors of this size operating with drum controllers and they have proved entirely satisfactory. A number of them have been in operation over a period of years. The control is adequate and simple and the maintenance cost very low.

Drum-type control has been employed on digging motors as large as 300 h.p., but in the writer's opinion better service could be obtained with other types of control for motors above 200 h.p.

For larger motors magnetic control or properly designed liquid rheostats can be used. There are a number of magnetic control equipments in successful operation on digging motors of 300 h.p. and 400 h.p. capacity, some of which have been in operation for two or three years. They have all proved satisfactory in operation and their maintenance cost has been low.

While experience with liquid rheostats on board dredges is as yet very limited, and there are some difficulties to be overcome there is no reason why, with proper design, their operation should not be successful.

I cannot agree with Mr. Rosenblatt regarding the excessive amount of resistance required with magnetic control nor with his statement regarding the fire risk incident to the use of resistors. The digging motors are provided with standard heavy duty resistors good for continuous operations at a speed reduction of fifty per cent, and these have proved entirely adequate; and in no case that I have ever heard of has there been any question of fire risk from these grids and there need not be, if they are so located that the air can circulate freely about them.

There have been a number of fires on dredges caused by electrical troubles; these, however, have nearly all been due to faulty installations of oil switches. As a result of these fires the Board of Fire Underwriters of the Pacific made a thorough investigation and issued a set of rules on "Standard Electrical and Fire Protection for Dredges." This set of rules is very thorough and in them no question is raised regarding the grids nor are special precautions required in their installation.

Mr. Rosenblatt mentions the use of intermittent rated motors for ladder hoist winch, and for raising the spuds or controlling the head lines, if these are used instead of spuds; if separate motors are used for these purposes the intermittent rated motor would be all that is necessary. As a rule, however, separate motors are not provided for this service. The ladder hoist winch is usually operated from the digging motor and this arrangement provides so much power that the ladder is raised much more quickly. The control of the spuds or head-lines is usually taken care of by the swing winch motor.

These operations are controlled by levers in the winch room. The swing winch is in operation all the time and an intermittent rated motor is not suitable for this purpose.

The power required from the digging motor depends on the size of buckets, speed of buckets, depth of digging and character of ground dug. The size of buckets varies from 2½ to 18.2 cu. ft. The speed from 18 to 22 buckets per minute. The depth from 10 to 70 feet below the water-line, and the character of ground from loose gravel and sand to hard cemented gravel. The size and weight of a dredge does not depend simply on the size of the buckets, but is also governed by the depth of digging and character of ground.

The largest and heaviest gold dredge yet constructed is, I I believe, one of the all-steel California dredges which has 16 cu. ft. buckets and digs to a depth of 70 ft. below the water line. This dredge has handled 325,000 cu. yd. in a running month of 30 days. I believe the highest record for material moved is at present held by the Boston and Idaho dredge, which has buckets of 18.2 cu. ft. capacity and has a record of over 400,000 cu. yds. in one month.

In point of size and power this dredge is not the equal of the large California dredge just mentioned, but has shallower ground and easier digging.

A. A. Miller: I do not have anything in particular to add to the technical part of this discussion, but I know that a great deal of the work of this character, the use of electric power in gold dredging, is being carried on in the northern possession of our Canadian neighbors across the line, in the vicinity of Dawson, Yukon Territory particularly; they have some of the largest gold dredges, in the world, I believe, which are being used, particularly by Mr. Boyle of the Boyle Concessions; they have built water power plants and transmission systems of their own for the purpose of furnishing these dredges with electric power. Unfortunately the site of operation is so far removed from us that we cannot get to them very frequently to know what they are doing, and the information apparently does not reach us. It would be interesting if we could get more detailed information from those particular dredges.

I believe there will be also in the course of the next year or so considerable activity in the vicinity of Nome in this same sort of work. I was told by a mining engineer who is familiar with conditions there that in the next two or three years there will be something like $5,000,000 taken out from a clearly defined area by dredging operations.

C. B. Rosenblatt: I am going to make this discussion as brief as possible, but there are a few things that I can't let go by. One of the gentlemen registered some objection to the use of alternating current. We all know that a direct current motor would be an ideal drive. Nobody denies that; but the gentleman does not look at this matter from the dredging point of view, he looks at it purely from the electrical engineer's standpoint, and that is one thing I particularly ask you gentlemen not to do when it comes to dredging. Direct current for dredges has been figured over and over again. I believe Mr. Gerry here went into that as carefully as any man possibly could when the Conrey Placer Mining Company decided to electrify. Engineers in California went into it carefully too. It can't be figured out any way to show a monetary profit under conditions of power supply that obtain today—and remember the dredge is in business to make money.

Mr. Shepard has a very good communication from San Francisco. There is only one thing about it that demands comment and that is that it represents California practise as advocated by two manufacturing companies. Mr. Shepard's remarks apply particularly to the type of dredge built by those two companies, which use certain motor drives that are arranged primarily for the use of standard motors, even for the digging motors. There is considerable question as to whether the drives used by these manufacturers are the best for a big dredge, but that is not a problem for the electrical engineer to discuss. Mr. Shepard mentions particularly the use of a wound-rotor motor drive for stacker as compared with the squirrel cage motor. That is a matter on which I said I expected some criticism from California because they have generally come to use the wound-rotor motor for that work. But remember the California climate is particularly favorable. It is all right to take a slip-ring motor and stick it up on the end of the stacker if you have a favorable climate and never get down below forty degrees above zero, but the conditions in Montana, Oregon, Wyoming and Alaska are different from that. Another thing Mr. Shepard does not take into account is the fact that the dredges with which he is concerned, have comparatively easy digging; while the Californians may not agree, I believe it is easier to dig the California gravel than it is the Northern clays, and Mr. Gerry brought that out when he said that his own opinions and observations in this matter had been backed up by the observations of practical dredge men.

There are good points about each kind of drive. Each may be particularly fitted for a particular installation. There is no panacea for this dredge work. I have tried to point out the considerations that apply most generally. We have to analyze each case by itself and find the underlying conditions that make the selection of particular apparatus most desirable, and while unquestionably, for Mr. Shepard's own conditions, he has selected very excellent electric drives for those dredges in California, yet they will not necessarily work with best success everywhere in the world.

DISCUSSION ON "ECONOMY IN THE OPERATION OF 55,000-VOLT INSULATORS" (CRAWFORD), SPOKANE, WASH., SEPTEMBER 11, 1914. (SEE PROCEEDINGS FOR AUGUST, 1914.)

(*Subject to final revision for the Transactions.*)

J. Harisberger: What brought about the development of testing insulators as mentioned in the paper, was a severe storm in the Puget Sound district last winter, causing a number of breaks in our transmission line where it goes through heavily timbered country, these breaks causing arcing grounds and breaking down insulators all over the system. We had been very proud of our record of uninterrupted service, and this trouble set me to thinking about aging of porcelain that has been so much discussed recently. I have been unwilling to admit to myself that there is such a thing as the aging of porcelain, and I do not believe it now. Last spring I made a trip down the Coast to visit operating companies that have been operating lines of 50,000 volts or over for some time, to get what information I could as to their experience. I visited eight companies and found but one man who was positive that porcelain deteriorated and gradually lost its dielectric strength. I found that the experiences of most of the companies visited were quite similar to our own. The porcelain of some of the insulators in service five to six years, on close examination, showed a mottled surface similar to that of Dedham china ware. On breaking the insulator, discoloration of the cracks to a depth of one-quarter of an inch was occasionally found. There is no doubt that this condition cuts down the insulating quality of the porcelain and these insulators should be weeded out before they are broken down by some disturbance on the system. During my absence, Mr. Crawford developed the method as outlined in this paper for locating such insulators. I believe that everyone having had experience in the operating of high-voltage transmission lines will agree with me that high-frequency disturbances such as are caused by arcing grounds, etc., are most to be dreaded. While in California, I spent half a day with Professor Ryan, of Stanford University, who showed me a practical demonstration as to what high-frequency currents will do. An insulator that would show practically no distress at 150,000 volts at 60 cycles, would be punctured in a few seconds when subjected to over 100,000 cycles and not over 25,000 volts.

It is quite noticeable on our system that the majority of failures are insulators cemented to iron pins. Over seven years ago I objected to cementing insulators to pins and designed a pin with a flexible top for screwing on 60,000-volt insulators. I was much criticised and was told that I would get into trouble on account of the metal expanding and breaking the insulator. We have some 20,000 insulators in service of this type of construction, and I have yet to hear of a failure on account of this type of pin.

M. H. Gerry, Jr.: The design of high-tension line insulators is now pretty well understood, but, of course, it is still a question of effective material and proper distribution. The most important of all is the distribution of electrical stress. This has been discussed many times in the Institute PROCEEDINGS.

V. H. Greisser: The principal thing in this paper of interest to me is the fact that the telephones can be used for delicate practical tests, and we are very fortunate indeed to be able to secure some such instrument that is sensitive enough to test insulators. Practically the only instrument of any use on high tension work previous to this, has been the oscillograph, and that has not been sensitive enough to be very useful in testing porcelain insulators.

A. A. Miller: I take it for granted that Mr. Greisser's last remark that the oscillograph does not afford the proper means of testing insulators referred to the work which Dr. Ryan has been performing in California, where he has used| very high frequencies, away beyond the natural periodicity of the oscillograph, and found that it was very easy to puncture porcelain insulators by using such frequencies. He has a laboratory in which he very effectively demonstrates the ease with which porcelain is punctured by means of these very high frequencies, boring holes right through an insulator. Professor Ryan's investigations I think will throw a great deal of light on that.

H. R. Noack: There has been a great deal of discussion upon the subject of aging of porcelain. I think there is some misconception of the meaning of the term "aging." As I understand it, aging applies particularly to a molecular change in the porcelain itself. Porcelain is a very inert matter and, so far as any studies which I have been able to make on the subject are concerned, there has never been noticed any molecular change within the porcelain itself. The effects commonly considered as aging, I am satisfied, have nothing to do with molecular changes, but are generally due to external influences. For example: porcelain insulators as used today are generally in combination with other materials, such as cement and steel or iron, and some of the changes noted under operating conditions undoubtedly are due more to the influences of a combination of these different materials with different characteristics than to any inherent change in the porcelain itself. Again, there is no known standard, to my knowledge, as to what constitutes perfect or ideal porcelain; different manufacturers have different standards in mixing, firing and in manufacturing, generally, so that there is no one standard which has yet been established as to what constitutes ideal porcelain. Many of the troubles which have been noticed may, in my opinion, be ascribed to improper firing of the porcelain, assuming, of course, that in the first instance the mixture was suitable to make perfect porcelain if handled properly in the subsequent manufacturing operations. It seems to me that, eventually, engineers will have to determine upon some standard for measuring perfect porcelain. An underfired piece of porcelain is, to a certain degree, porous. The porcelain is almost invariably covered by a glaze, which is a glassy structure and protects the body of the porcelain from external influences; such as, moisture and gases, but under operating conditions the glaze may be eventually injured, and even though it is not injured, there are some portions of the porcelain which are not covered by the glaze, due to manufacturing necessities, so that gradually there may be absorption of moisture, which, when subjected to heating influences due to electric currents, may cause expansion to such a degree as to gradually develop minute cracks, and these, though microscopic at first, will eventually grow in intensity, and finally allow the porcelain to puncture. On the other hand, the porcelain is sometimes over-fired, in which case it takes on a glassy structure and is not capable of resisting the influences of alternate expansion and contraction to the same degree as perfect porcelain.

The question of "aging" is one of great importance and, as I said in the beginning of my remarks, I do not believe that it has been demonstrated that any such phenomenon exists, but that the difficulties arising from so-called "aging" are due to external influences.

T. R. Cornick: I was with the Mexican Light & Power Company when its line was first put into operation. We had approximately 500 miles of 60,000-volt circuit and later 40 or 50 miles of 20,000-volt circuit. I was there for approximately five years after these lines went into operation and I do not think that I ever discovered any "aging." We did have a lot of trouble due to electrical disturbances and I should say approximately twenty punctures. Those punctures took place, however, when these electrical disturbances were on; therefore we did not call them the "aging" of the insulator. That line after being in operation at 60,000 volts for several years was increased to 80,000. The insulators of course were changed. To start with we used the Rio type, 14 1/2 in., which was changed to, I think, 18 in. when they went to 80,000 volts. Since they went to 80,000 volts they have had no appreciable increase of trouble. Our troubles all took place before we put on the ground-wire. After we put on the ground-wire our troubles decreased, from, you might say, every day of the rainy season (during six months of the year) to approximately three cases of trouble during the rainy season. We, therefore, took it that the trouble was purely and simply the lightning and not trouble with the insulators. Therefore, I think Mr. Noack is right in his discussion in that it isn't a case of "aging" of the insulators but is doubtless a case of poor mixing, or poor manufacture.

P. M. Lincoln: I ask Mr. Cornick if the ground wire was overhead?

T. R. Cornick: Yes, overhead ground wire.

L. T. Merwin: I can't offer anything from experience here in Washington, because the line of the company with which I am connected has been in operation only 17 months. I might say, however, the insulators that are now being put on the market are certainly remarkable for the factor of safety that is offered. I speak now from the experience of an instance on our line shortly after it was put into operation. It was on June 17th of last year, when we had a turbine runaway in our plant. After we had patched things up, and got the line in operating condition again, or rather got the plant in operating condition again, we tried to repeat the runaway under hand control, and one of the results that we obtained by interpolation and extension of the graphic lines on our charts showed that we must have had during that runaway, an impressed voltage on the line of something between 150,000 and 200,000 volts. The line is of wooden-pole construction with steel-core aluminum conductors and pin type insulators, with four strain units in a dead end. The pin type insulators had cemented lead thimbles in the top of the insulators; the lead thimbles receiving a ¾-in. steel pin. Now, since that runaway and the impressing of that extremely high voltage on our line we have not had a single breakdown, neither did we have a single break-down up to that time. The line was put in operation on the 25th of April, 1913, and on June 17th the runaway occurred with this high impressed voltage. It is now approximately fifteen months, and we yet have to experience our first insulator failure.

I might also add that on another occasion our insulators withstood a severe arcing ground for 1¾ hours before the faulty section could be cut out by open air switching. This occurred quite recently with no bad results.

Incidentally our lines are delta-star connected with ungrounded neutral, and I was able to carry load through this very severe arc. Now it is, I should say, a remarkable thing that insulators have such a large factor of safety as to stand a voltage of two to three times the working voltage. The farmers along our line described the spectacle as being awe-inspiring. Of course any high arc is awe-inspiring to the layman; but from reports our line must have been lit up with corona from one end to the other and apparently looked like a solid streak of fire from the White Salmon river clear through to Camas. So if there is any aging in insulators it certainly has not appeared yet in the seventeen months of operation, and there certainly were no immediate bad results.

L. J. Corbett: There is one point that I would bring up here which has not been touched upon as yet, and that is the matter of glass insulators and their possibilities. We have heard thus far only regarding the changes in the porcelain insulators. The porcelain manufacturers have been busy for some time and have been doing very effective work, and they appear to have a very reliable product at the present time. It seems to me that glass with its superior insulating qualities should be worked upon a little more by the glass manufacturers and it may be possible that a more effective insulator, an insulator more constant in its qualities, could be developed. The objection I believe is the uncertainty of glass in its mechanical strength. The difficulty about the porcelain is the uncertainty in its electrical strength, and I would like to see in the future more development in that line if there are actual possibilities.

Ralph W. Pope: I have been thinking of glass during this discussion. Mr. Field, who was one of the early electrical engineers in California, stated that the possibilities of glass for long distance transmission insulation had been overlooked; and I may say, in reply to Mr. Corbett, that the manufacturers have gone into this question very thoroughly, and some of the data as regards tests will be found in the PROCEEDINGS of December, 1912. If there is any doubt as to the relative qualities of porcelain and glass it would be wise to put them in operation at the same time and study the results simultaneously so that if there is a possibility of the glass insulator being better it could be ascertained in that way. In the discussion which took place at the Cooperstown convention on insulators the question of mixing of porcelain came up for consideration, and it appears to have been maintained that it wasn't the business of the electrical engineer to go into the mixing of porcelain, but that that was the work of the ceramic engineer. There is no doubt but that the manufacturers of porcelain insulators are investigating this; but, as it appears to me, it is a rather difficult matter, and the committee found it so, to arrive at a standard of perfect porcelain. The mechanical stress is a very important feature, and I think that is particularly what the manufacturers had in view in the construction of glass insulators. Those can be obtained now, I believe, in almost any form, and I think it would be worth while for engineers to test out their possibilities.

M. H. Gerry, Jr.: There is considerable misunderstanding on the subject of glass insulators. Glass is weaker mechanically than porcelain, and is also subject to internal strains, which may cause cracking when exposed to varying temperatures. The internal strains can be obviated to a considerable extent by proper design and can be materially reduced by careful annealing during manufacture. Glass insulators in many instances will give most excellent results; they are always cheaper and often better than porcelain insulators. I have had personal experience with over 200,000 glass insulators under operating conditions at voltages from 25,000 to 70,000, and I have never known an electrical failure traceable directly to the material. Where trouble has occurred, it has been due either to defective design, improper annealing or too great mechanical strain on the insulator. It would be impossible to make a statement of this kind for porcelain, as a great many electrical failures have been due to defective material.

A. A. Miller: I ask Mr. Gerry whether or not he considers the new form of insulators, in which there are disks placed in series to each other, contributes in any way to the elimination of these internal strains. In other words, the disks, it seems to me, would contribute to the elimination of these internal strains a great deal more than the petticoat insulators.

M. H. Gerry, Jr.: It is entirely a question of proper annealing of the glass during manufacture and the relative proportions of the different parts of the insulator.

E. Woodbury: I ask Mr. Harisberger if he can tell how they would apply this test of the telephone receiver in case of a tower line or a wooden structure having pins grounded.

He also mentioned that probably it was bad practise to have cemented pins in the insulators; in view of this, do they use insulators with cemented-in metal thimbles, or are the insulators screwed directly onto the pins?

He also mentioned link-type strain insulators. It is my understanding that that type is not now manufactured, and that all suspension type insulators, therefore, would have cement. In line with his remarks on insulator troubles, we have been in the habit of shutting down at convenient times our lines having pin-type insulators, and tapping the insulators with a stick to determine the cracked ones. On the coast where we had considerable trouble with burning off of poles and cross-arms on a 15,000-volt line, we have connected the iron pins together with a wire and have stopped absolutely all the burning of poles.

J. Harisberger: I have not had any experience with glass insulators for high-voltage lines, but if anyone is qualified to speak on that subject, Mr. Gerry is.

We have had no occasion for locating faulty insulators on tower lines, as we have only some 12 miles of tower line and the insulators have only been in service a little over two years and have given absolutely no trouble.

In answer to Mr. Woodbury's question, I will say that insulators cemented to iron pins have a threaded 1$\frac{3}{8}$-in. pin hole. Whenever an insulator is broken, we do not change the pin, but place a threaded sleeve of soft metal over the top of pin and screw on a new insulator. This sleeve was designed for this purpose and costs about two cents.

DISCUSSION ON "A DISTRIBUTION SYSTEM FOR POWER PURPOSES" (NIMS), SPOKANE, WASH., SEPTEMBER 10, 1914. (SEE PROCEEDINGS FOR AUGUST, 1914).

(Subject to final revision for the Transactions.)

J. B. Fisken: It was my good fortune last year at the Pacific Coast Convention to Vancouver to see quite a good deal of the work that Mr. Nims had done with this ductless cable. I have noted some of the points on which I would like to hear some discussion. These are: the relative cost of ductless and duct lines, the use of the various insulations, such as paper, varnished cambric, and rubber and the relative advantages of the wire of the shape he mentions as against round wire; I also ask Mr. Nims in replying to state if he knows what is meant by lead cable costing $606 a thousand feet to which he referred.

It appears to me that this system of ductless underground cable is eminently suitable for distribution in residential districts, but I don't see how it can be practicable in congested districts such as the business part of the various cities where you might have as many as thirty or forty cables in one duct line; it would appear to me that there would be many operating difficulties—or, rather, maintenance difficulties in keeping such a lay-out as that in commission.

P. M. Lincoln: This matter of the kind of cables that Mr. Nims is using is probably the most interesting point in the paper.

I ask first if he has any difficulty in locating faults and if he can locate them so that he does not have to dig very much when he comes to find the fault and repair it; also I presume that this type of installation would not be at all applicable where you have to take up pavement to make repairs—in that case I presume it would be out of the question.

The question which Mr. Nims mentioned, of this being much more capable of getting rid of heat, is an important one. When the Niagara Falls plant was installed 2200 volts was the voltage and it was considered high at that time—1893-4;—those were 3740-kv-a. generators, and there were ten of them, which gave a whole lot of current to take care of. That current was distributed to our various customers at 2200 volts and it was distributed through cables in ducts, and the problem of getting rid of the heat in those ducts was at that time and still is one of the most difficult problems which has to be dealt with. I can assure you that any means of increasing the capacity of the cable, so far as the heat is concerned, appeals to me on account of my experience there. We made many duct conduits in the early days, some of them as many as 36 ducts, and we found the cables in the middle of those many-duct lines would have an exterior temperature.rise of 50, 60 or 70 deg. fahr. to begin with, some of them more than that, so that you can see that the problem of getting rid of the heat, particularly the heat in those conductors which ran in the interior ducts of the conduit, became a very serious one. They have even gone so far as to circulate water in some of the ducts in order to get rid of the heat. This is really an important problem, particularly where large amounts of power have to be dealt with at relatively low voltages.

F. L. Rohrbach: Regarding the cost of underground systems, which would include a duct and manholes, I do not think there is any question but what Mr. Nims has used the cheapest method in his system at Vancouver; but I ask Mr. Nims if he has considered the case of using ducts and leaving out manholes (except those necessary for switching); also the use of lead-covered cables, and what that would mean? I suppose this cable could be exposed at points where the manhole would naturally be built, so that in case of trouble it will only mean digging down at each manhole, or where the manhole should be, and pulling out the cable that is in trouble. It would mean also that you could watch the size of your cable; and when necessary it would be easier to take out a small cable and replace it with a larger one. Now, I do not know exactly the difference in cost between this steel armored cable and lead-covered cable, but judge it would be about ten cents per foot, that is for the same size cable used with the steel armor and cable used in duct. Where you have three ducts in one line, they can be laid cheaper than three lines of single duct, I would figure the saving in cable roughly at ten cents a foot; thus lead-covered cable would be probably $7,300 cheaper. Another place you could save would be in the cost of the straight-joint boxes; that would be $1100.00 over the other method, as I understand these boxes are a means of connecting the armor on each side of the lead sleeve and keeping it continuous.

I do not understand the items under the " six railway crossings " and " ninety-six street crossings." There are no lengths given and I have no idea what the total distance is. If they are ordinary streets of 75 or 100 ft. it seems to me the cost is high, as I understand that is where the wooden duct was installed. Of course I know nothing about the labor costs in Vancouver, but here in Spokane I would estimate that a single fiber duct surrounded with concrete could be installed for about sixteen cents per duct foot, and wooden ducts for twelve or thirteen cents. Of course my idea in installing this lead-covered cable, in a duct throughout the whole system, as well as at crossings, is simply for the purpose of being ready to pull out in case of trouble; and I think Mr. Nims will find that if there is a breakdown in the cable there will be some difficulty in locating the point of trouble. I have found that a good many eastern companies in testing for trouble use what they call the " cut-and-try " method. That does away with any complex test. Most of them simply go out and cut the cable probably at the center and find out which half it is in and then trace it back. I think this would probably be the case at Vancouver, although there may be some other method of doing it. There is one method which is used by simply putting a current on the conductor that is in trouble and then reversing the current. You go along in each manhole with a compass held close to the cable, and when you come to the point where your compass does not vary, you pass the point of trouble and you know which section it is in; but you would be unable to do that with armored cable.

I suppose that Mr. Nims has certainly considered the conduit and manhole construction, and if he has I would like to hear approximately what the difference was in his estimates, and also if he has considered the duct alone leaving out the manhole, because it would be a simple question to leave a four-foot section and have your joints there so that you could easily get down and uncover your cable. Of course I understand that by doing this you would have to cut your cable up in smaller pieces, have more joints, but you would get rid of making your additional joints over your lead-covered cable which you do with these straight joints. I think that here in Spokane I could come pretty close to this total cost, and put in a single duct leaving out the manhole.

There is another question: Mr. Fisken said something about a large number of cables. I think it would be entirely out of the question to put in many cables; in fact, I do not know but what four would be too many, and especially as the size of the cable is not stated; for it would depend entirely upon the size of the cable. When you get a cable from about 1.2 inch to 1.7 inch the additional cost of the armor runs up considerably, varying from ten cents if the lead sheath is 1.2 inches in diameter. up to 19 or 20 cents, going up very rapidly to 1.7. The cost of the duct in fibre (fibre and cement) is about 16 cents; that is not including the trenching because I have taken for this estimate that the trenching is already done; I have only taken the cost of installing the duct, which will run from probably 16 cents down to 10 cents, depending on the number of ducts. A wooden duct would be cheaper, possibly from fourteen down to seven or eight cents.

The amount of heat dissipated by this cable is placed approximately at 15 per cent over one working in a conduit. I would like to ask Mr. Nims if he has made this test, whether it is between armored cable in a duct and armored cable in the ground; or whether it is between armored cable in the ground and lead-covered in the duct. The additional insulating (jute) over the armored cable would probably cause an increase in heat or seven or eight per cent; that is, it would be harder to get rid of the heat due to the doubling, practically, of the insulation.

And regarding electrolysis, there is no question that the armor would be some protection against electrolysis, but still if electrolysis was present the armor might give way and the lead would possibly be eaten up, or if electrolysis was not sufficient to eat away the armor it probably would not injure the lead so quickly.

C. S. MacCalla: I had a little indirect experience some years ago in the system which was in the city of Sydney, Australia. The New South Wales government .owns and operates the street railways in Sydney, which is a city of about three-quarters of a million; I happened at that time to be working for an American contractor who was installing a three-phase generating apparatus and substations. The cable was placed by an English contractor; it differed from Mr. Nims's cable and was considerably inferior to it; it had no iron armor and no insulation outside other than a little bitumen. The cables were laid in open trenches, I think about as many as eight in a trench, and were surrounded with a bituminous material and covered with treated plank. This cable was installed some months before the generating apparatus was ready for operation, and when they came to put the current on we had all kinds of trouble; and when investigated it was found that electrolysis had destroyed a large portion of the cable. If I had been the operating man at that time I would have been very thankful for a few ducts to pull out the cable. The whole city, which was largely paved, had to be dug up, the streets were torn up for some time, and the system had to be practically relaid.

H. V. Carpenter: I have had a little experience along this line, and I might state one instance which shows the durability of the steel armor. We have one cable line across the college campus, in which the cable is laid about two feet underground; during the excavation for our new engineering building recently they got over the line too far, and I found them tugging away at the cable with a plow and team, but they hadn't hurt it any, so we moved it over out of the way. The cable showed no injury at all. It seems to me that in cases of that sort, where it is in a park or some place where there is no pavement, and there is no danger of electrolysis or any of those things, that the use of the buried cable is very satisfactory.

Regarding the location of faults, I would like to say that the system which is now in use quite commonly by water companies, for locating troubles in pipes, could be used for locating faults in this cable. That is, put a current through the cable to the point where the fault occurs, and then take a coil with a good many turns on it and connect up the telephone receiver, walk along the ground over the cable, find the fault and dig it up and fix it.

P. M. Lincoln: About that last-mentioned method of locating faults, I have had some experience with it. That very same scheme was tried by the Niagara Falls Power Company back in about 1896 or 1897, and the trouble we found was that the location of the fault thereby was not definite. There would be at the point of the fault a slight diminution of sound in the telephone but you would hear the telephone still buzzing for five hundred feet beyond the fault, and we found that the location of the fault was so indefinite that we had to abandon that scheme and locate our faults by some other method.

H. V. Carpenter: I think the accuracy with which that location could be made would depend considerable on whether the inductive coil was working by electrostatic action or by electromagnetic. If a current of sufficient strength is put through the cable to the point where the fault is located, so that the action is not electrostatic, then the trouble would be located quite accurately.

P. M. Lincoln: The influence of the cable upon the telephone is due to electromagnetic induction entirely, and the difficulty was undoubtedly due to the fact that the current after it left the fault followed the cable and got away into the ground rather gradually and the telephone would not distinguish whether the current flows in the copper conductor or in the lead sheath.

Edward Woodbury: The paper states: "Water for cooling is taken from the city mains." I wonder if they waste that water or whether they attempt to save it. We have a small pump and cooling tower and the water is circulated; then for an emergency we have a city supply and in case the motor stops running the city water is turned on automatically.

G. B. Rosenblatt: Regarding water-cooled transformer substations, I wonder whether, where Mr. Nims comes from, they have any trouble with their cooling system from freezing? The matter of climatic conditions might be of further interest. I wonder how much freezing of the ground they have to contend with when they have any repair work to do in winter on the cable system.

John Harisberger: The use of cables in trenches without ducts appeals to me, especially as to first cost, if it is not intended to make numerous connections.

The problem of cooling water for transformers has confronted most operating companies. Use of city water is expensive, a cooling tower is not a perfect arrangement. We have a rather novel arrangement in our Everett substation to prevent the waste of water. There are two pipe lines, one at 125 pounds pressure and one at 80 pounds pressure. The water for the transformer cooling coils is taken from the 125-pound line through a reducing valve which reduces the pressure to 90 pounds, and is discharged into the 80-pound line. This arrangement has proven quite satisfactory.

One of the gentlemen mentioned a cut-and-try method for locating trouble in cables. I wonder if Mr. Nims had any facilities for sectionalizing his 60,000-volt overhead lines, such as pole-top switches. If pole-top switches are used, has he found them satisfactory?

L. J. Corbett: This paper relates to the actual engineering features of an installation for a definite purpose. We can appreciate a difference between the installation for power alone, and one for both lighting and power. When the lines are opened temporarily or the voltage fluctuates due to some heavy load coming onto a system of the latter class, there may be a good deal of trouble caused, and complaints will be heard from the lighting customers. On a purely power load the fluctuations are not so noticeable, and while shutdowns may cause inconvenience, this is not comparable with a similar one on a lighting system, and for these reasons certain economies can be effected in the installation of such a system. Going still further, there are yet other systems which take greater liberties. In the case of a private manufacturing plant, for instance, which is generating or even buying its power and distributing it through its own system, liberties are sometimes taken with standard construction which would not be considered at all by a power company serving an exacting public. In Mr. Cotton's address which was given yesterday, we heard the term " near confiscation." We have in such cases as these at times a condition of " near unsafeness," and the limit is quite often approached rather closely.

I recently had occasion to make an estimate upon a system to use steel-armored cables, and found the cost to be somewhat more than that of lead cable and iron pipe conduit. The difference was not great, but it appeared to me to be in the wrong direction.

As has been brought out, quite frequently tests are made so closely that one can locate a fault within a very few feet, if the data regarding the length of line, distances, etc., are definitely known. In one or two of the cases just mentioned where the coil and telephone receiver were not successful, it occurs to me that possibly the reason for not locating the fault more closely might be this: If you have a large number of cables in a set of ducts, only one of which is faulty, your instrument will not be so sensitive as it would be in a case where there is but one cable, as in the campus system mentioned by Professor Carpenter.

Paul Lebenbaum: Relative to the advantages of sector as against round conductors, I know of an instance in which an operating company had a duct line that carried the maximum size of cable using round conductors, the number of ducts being limited by physical conditions. It being necessary to increase the capacity of this line, without resorting to a new route, cables of the sector type, having the same outside diameter as the round type, were substituted for the latter, and the desired increase in capacity was thus obtained.

E. Woodbury: I ask Mr. Nims if a sector cable costs more than the ordinary round type.

H. W. Carpenter: I ask how small size the sector cable is that is used; it occurred to me that if the sizes were carried down too low the corners of conductors would offer considerably greater tendency for electrostatic stresses to break through the insulation there than you would get with the round section.

F. L. Rohrbach: There is one company that I know of which does not recommend making a sector cable in which the conductor is less than 1/0. They claim that conductors smaller than 1/0 are apt to cause too sharp bends or points, which introduce the corona effect and sooner or later cause the cable to break down. This same company recommends an " oval " rather than a " sector " cable, especially for the smaller sizes.

These odd-shaped cables were first introduced for the purpose of saving duct space, and were therefore made in the larger sizes. For example, a 4/0 three-phase 15,000-volt ordinary cable is as large as you can install in a 3½-inch duct, but by making a " sector " or " oval " cable, you can probably increase the conductor to 350,000 cir. mils. For my part, I can see no reason, but rather an objection, for making a small size cable in these special shapes. My objection would be that you decrease the circumference of the lead sheath, and thus cut down the radiating surface. I think this cable used at Vancouver was made in " sector " shape mainly to hold down the cost of the armor.

M. T. Crawford: I ask Mr. Nims what types of lightning arresters are used on the 12,000-volt lines of the system and what operating success has been secured. On 13,000-volt distributing lines for rural light and power on Puget Sound we have in some cases installed horn gaps without resistance of any kind and set for about three times line voltage. This type of equipment is only installed on the ends of branch feeders into rural districts where it has been necessary to keep the cost of construction down. Electrolytic lightning arresters are invariably used on the busbars in the distributing station. As the 13,000-volt feeders frequently run underneath 55,000-volt lines for some distance after leaving the station, there is the possibility of accidental contact between circuits, as well as the trouble from lightning to care for. A short circuit on the ends of these light capacity 13,000-volt lines will only trip the circuit breaker and cause a short interruption, which is preferable to damaging distributing transformers. I should like to hear other engineers' ideas on this subject.

MIDWINTER CONVENTION, NEW YORK, FEB. 17-19, 1915 See p. 29, Sec. I

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Vol. XXXIV **February, 1915** No. 2

A. I. E. E. Third Midwinter Convention, February 17-19, 1915

The third New York Midwinter Convention of the American Institute of Electrical Engineers will be held at Institute headquarters, Engineering Societies Building, 33 West 39th Street, New York, on Wednesday, Thursday and Friday, February 17, 18 and 19, 1915. The list of papers to be presented follows. All of these papers, with the exception of Nos. 10, 11 and 12, are published in this issue of PROCEEDINGS. Reprints of all papers to be presented will be available without charge at the technical sessions.

Registration

The registration headquarters will be in the lobby of the Engineering Societies Building. In order to facilitate the handling of mail, telegrams and inquiries received for Institute members and others in attendance at the convention, it is desirable that members register themselves and their guests immediately upon their arrival. Upon registration each member and guest will receive a badge bearing his or her name, which for convenience in identification should be worn during the convention.

Wednesday, February 17

10.00 A.M.

The Convention will be opened by an introductory address by President P. M. Lincoln, after which the following papers will be presented:

1. *The Characteristics of Electric Motors Involved in their Application*, D. B. Rushmore.

2:30 P.M.

2. *Effect of Moisture in the Earth on Temperature of Underground Cables*, by L. E. Imlay.
3. *Oil Circuit Breakers*, by K. C. Randall.
4. *Comparison of Calculated and Measured Corona Loss Curves*, by F. W. Peek, Jr.
5. *A* 100,000-*Volt Portable Substation*, by Charles I. Burkholder and Nicholas Stahl.

Members attending the convention are cordially invited to attend the session of the American Institute of Mining Engineers devoted to the " Use of Electricity in Mines " to be held on the 5th floor of the Engineering Societies Building Wednesday afternoon, February 17th.

8:30 P.M.

The subject of this session will be "The Status of The Engineer." The opening address will be presented by Mr. Lewis B. Stillwell, followed by addresses on the subject by Messrs. E.W. Rice, Jr., E. M. Herr, Alexander C. Humphreys, John Hays Hammond, George F. Swain, H. G. Stott, and J. J. Carty.

Thursday, February 18

10:00 A.M.

6. *Distortion of Alternating-Current Wave Form Caused by Cyclic Variation in Resistance*, by Frederick Bedell and E. C. Mayer.

7. *Dimmers for Tungsten Lamps*, by Alfred E. Waller.
8. *Searchlights*, by C. S. McDowell.

2:30 P.M.

Thursday afternoon will be devoted to a trip to the new power station of the United Electric Light and Power Co., 201st Street and Harlem River, and to other places of engineering interest.

7:00 P.M.

Dinner Dance at the Hotel Astor.

Friday, February 19

10:00 A.M.

This session will be devoted to the subject of "Electrical Precipitation" and the opening address will be delivered by Dr. F. C. Cottrell, who will give a historical sketch of the steps in the development of this phase of the art.

9. *Electrical Precipitation—Theory of the Removal of Suspended Matter from Fluids*, by W. W. Strong.
10. *Theoretical and Experimental Considerations of Electrical Precipitation*, by A. F. Nesbit.
11. *Practical Applications of Electrical Precipitation*, by Linn Bradley.

2:30 P.M.

12. *Electrical Porcelain*, by E. E. F. Creighton.

Dinner-Dance, Thursday Evening, February 18th, 7:00 P. M.

In accordance with the custom established in previous years, of having a social function in connection with the convention for the benefit and entertainment of the members and guests, the New York Reception Committee has arranged for a subscription Dinner-Dance at the Hotel Astor, Broadway and 44th Street, New York, on Thursday evening, February 18th, at seven o'clock, in which all members and their guests are cordially invited to participate. The arrangements provide for eight persons at a table. Dancing will follow immediately after the dinner. The subscription price is $3.50 per person. Applications for reservations should be made promptly to the New York Reception Committee at Institute headquarters, and should be accompanied by the names of guests.

Inspection Trip
Thursday Afternoon, February 18th

There will be no technical session on Thursday afternoon, in order that the members may have an opportunity to visit the power station of the United Electric Light and Power Company, 201st Street and Harlem River. The party will be made up in the lobby of the Engineering Societies Building and will leave promptly at 2:30 p. m., going to the power station by special motor buses.

Facilities at Institute Headquarters

Attention is called to the facilities available for members at Institute headquarters on the tenth floor. These include reading and writing rooms, the use of rooms for conferences or committee meetings, local and long distance telephone service, the receipt and forwarding of mail and express matter, and stenographic service when practicable. Information regarding hotels, railroads, and points of interest in and about New York is also available. These facilities are at the disposal of members not only during the convention, but at all times during office hours.

Library

The Library, which contains the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the United Engineering Society, is located on the two upper floors of the Engineering Societies Building. The Library is conducted as a free public library of reference, and now contains about 60,000 volumes, and over 600 sets of periodicals.

One of the most important features of the library is the research department, which places the facilities of the library at the disposal of out-of-town members. Upon application to the library, bibliographies are prepared on any desired engineering subject, and abstracts, translations or photographs are furnished. A small fee is charged for this work.

Cleveland Meeting, March 18-19, 1915

Preparations are well under way for a two-day meeting of the Institute to be held in Cleveland, Ohio, Thursday and Friday, March 18-19, under the auspices of the Industrial Power Committee and the Cleveland Section. The sessions will be held at the Hollenden Hotel.

Following is the tentative program of papers to be presented:

" The Principles of the Application of Electricity to the Ore-Handling Industry," by C. T. Gilpin, electrical engineer of the Wellman-Seaver-Morgan Company, Cleveland.

" The Rubber Industry—Electrical Applications and Allied Problems," by A. P. Lewis, electrical engineer of the Goodyear Tire and Rubber Company, Akron, Ohio.

" Fractional Horse Power Motor Loads," by H. A. Pratt, manager Industrial Power Division, Westinghouse Electric and Manufacturing Company, New York.

" Line Disturbance Caused by Special Squirrel Cage and Wound-Rotor Motors when Starting Elevators or Hoists," by J. C. Lincoln, president, Lincoln Electric Company, Cleveland.

"Current, Torque and Power Factor Characteristics of A-C. Elevator Motors," by J. F. Lincoln, vice-president, Lincoln Electric Company, Cleveland.

" The General Principles of Motor Application," by D. B. Rushmore, Power and Mining Engineering Department, General Electric Company, Schenectady, N. Y.

" Some Troubles Encountered in the Operation of Carbon Brushes on Direct-Current Generators and Motors," by E. H. Martindale, sales engineer, National Carbon Company, Cleveland.

On Thursday night, March 18, a banquet will be given at the Hollenden Hotel. The present plan is to hold the technical sessions Thursday forenoon and afternoon and Friday forenoon and afternoon. Friday evening will be left open for members to make their own engagements. Interesting inspection trips will be arranged for Saturday, and perhaps also for Friday afternoon.

Those who plan to attend the meeting should make their own arrangements for reservations directly with the management of the Hollenden Hotel.

The complete program for the meeting will be printed in the March PROCEEDINGS.

Pittsburgh Meeting, April 15-16, 1915

A two-day meeting of the Institute is to be held in Pittsburgh, Pa., April 15 and 16, 1915, under the auspices of the Industrial Power Committee and the Pittsburgh Section. The program for this meeting will be published in the March PROCEEDINGS.

Inauguration of the Engineering Foundation

On Wednesday evening, January 27, 1915, in the auditorium of the Engineering Societies Building, occurred an event noteworthy in the annals of engineering—the first public announcement of the generous gift of $200,000 by Ambrose Swasey of Cleveland, Ohio, given as the nucleus of a fund to be known as the Engineering Foundation, to be " devoted to the advancement of the Engineering Arts and Sciences in all their branches, to the greatest good of the Engineering Profession, and to the benefit of Mankind."

Mr. Swasey's gift was made through the United Engineering Society, for the benefit of the entire engineering profession, and the announcement was made at the meeting by President Gano Dunn of the United Engineering Society, that the administration of this fund will be entrusted to the Engineering Foundation Board, composed of eleven members. These members will be elected by the Board of Trustees of the United Engineering Society, and will include two representatives each from the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, two members chosen at large, and the president of the United Engineering Society, ex-officio. Only the income of the fund will be used.

Dr. Henry S. Pritchett, President of the Foundation for the Advancement of Teaching, made an address, in which he said that Mr. Swasey's gift was unique because it was not donated as such gifts usually are, to an institution of learning, but to working engineers, and because it is the first of its kind given by an engineer to be managed by engineers for engineers. Addresses were also made by Dr. Robert W. Hunt, Past-President of the American Institute of Mining Engineers, Mr. Charles Macdonald, Past-President of the American Society of Civil Engineers, and Dr. Alexander C. Humphreys, Past-President of the American Society of Mechanical Engineers, who formally accepted the gift on behalf of the United Engineering Society.

Following his announcement of the name of the donor, which until then had been known only by the few men concerned in the formation of the Engineering Foundation, President Dunn asked Mr. Swasey to address the gathering. Greeted by prolonged applause, Mr. Swasey modestly disclaimed praise for his gift, and bespoke appreciation for the engineers who had worked out the method of organization.

On Tuesday evening, January 26, a testimonial dinner was tendered to Mr. Swasey by the President and Board of Trustees of the United Engineering Society, at the University Club, New York. Mr. Gano Dunn, president of the United Engineering Society, presided, and brief addresses were made by representatives of the four national engineering societies which will be represented on the Engineering Foundation Board.

Ambrose Swasey, the donor of the initial fund for the Engineering Foundation, is widely known as the president of the Warner and Swasey Company of Cleveland, Ohio, prominent machine tool builders and the foremost builders of telescopes in the world. Among the instruments which they have designed are the famous Lick, Yerkes, and United States Naval Observatory telescopes, as well as the great 72-inch reflecting telescope for the Canadian Government. Mr. Swasey is also known for his practical efforts in aid of scientific education and the advancement of his profession. He is the inventor of a number of instruments used by the United States Government in the coast defense. He is a Past-President of the American Society of Mechanical Engineers, a member of the Institution of Mechanical Engineers of Great Britain and of the British Astronomical Society, and a Fellow of the Royal Astronomical Society. In 1900 Mr. Swasey received from the French Government the decoration of the Legion of Honor for his achievements in the design and construction of astronomical instruments, and in 1905 the degree of Doctor of Engineering was conferred upon him by the Case School of Applied Science.

1915 Year Book

The Institute Year Book for 1915 has been published and may be obtained free of charge by any member upon application to the Secretary, 33 West 39th Street, New York, by mail or otherwise.

The book, which is published primarily for distribution to non-members in connection with the work of the Membership Committee, contains the constitution, by-laws, lists of committees and members, and considerable other general information relating to the activities of the Institute.

Increase of Membership

There were 359 applications for membership received during the last three months of 1914 as compared with 242 in the corresponding period of the preceding year. This increase of 48 per cent is a direct result of the activity of the Membership Committee of the Institute and the various local membership committees of the Sections. It also clearly indicates that there are still large numbers of desirable prospective members throughout the country to whom the many advantages of Institute membership should be presented.

An analysis of these 359 applications indicates that the high standard of membership is being maintained, and that all branches of electrical engineering continue to be represented in the additions to our membership. The following is a classified summary of this analysis:

Operating Engineers with Public Utility Companies	174
Engineers with Manufacturing Companies	114
Professors and Instructors	26
Executive Officers	24
Consulting and Contracting Engineers	13
Miscellaneous	8

The geographical analysis shows that 324 of these applicants are located in the United States, 17 in Canada, 6 in the Canal Zone, 3 in Japan, 2 each in England and India, and one each in New Zealand, China, Panama Republic, Honduras and Argentine Republic.

The applications from the foreign countries indicate the high value placed upon Institute publications by engineers residing abroad, inasmuch as these publications constitute the principal tangible advantage of membership to foreign members.

Thirty-three States are represented by the applications from the United States. This widespread interest in the work of, and service rendered by, the Institute is due largely to the opportunity for participation in the numerous meetings of the local Sections of the Institute that have been organized in 31 cities throughout the country. These meetings and the other sessions and conventions are now so widely distributed geographically that a much larger proportion of the membership can conveniently attend meetings than was the case before the local Sections were organized, thus enabling these members to extend their acquaintanceship and to enjoy social intercourse with their fellow engineers as well as to discuss their technical problems with them face to face.

Many other advantages of membership in the Institute are referred to in a pamphlet describing the objects, scope and work of the Institute, which will be sent to anyone interested, upon receipt of request by any member of the Membership Committee or by the undersigned.

F. L. Hutchinson,
Secretary.

Plans of National Joint Committee on Line Construction

For the purpose of completing its organization and laying out its working program the National Joint Committee on Overhead and Underground Line Construction held a meeting at the headquarters of the American Institute of Electrical Engineers on December 16, 1914. According to present plans this Committee will prepare specifications or suggested practises or perhaps recommend modifications of existing regulations relating to the following subjects:

1. Underground and undergrade crossings.
2. Crossings of electric wires over electric railway tracks.
3. Crossings of trolley contact wires.
4. Overhead crossings of wires or cables of telegraph, telephone, signal and other circuits of similar character over steam railroad rights of way, track, or lines of wire of the same classes.
5. Overhead crossings of electric light and power lines.

6. Parallel lines.

Specifications covering subject No. 4 already prepared by an earlier joint committee representing various interests are now being considered for adoption by the National Joint Committee. Subject No. 5 has been covered by the present standard specifications, the edition adopted and published by the American Electric Railway Engineering Association being the latest revision. The other subjects are new, and specifications relating thereto will have to be prepared by the committee, which desires to enlist the cooperation of all persons and associations interested in any subject pertaining to line construction, with the object of preventing duplication of work and insuring uniformity in the specifications adopted by the various associations, thereby avoiding all unnecessary conflicts. It is the desire of the committee to be looked upon more or less as the court of last resort in the formulation and interpretations of specifications, and as such it would like to receive the hearty support of all interests concerned.

The National Joint Committee is made up of official delegates and alternates from the following organizations:

American Railway Association.

American Railway Engineering Association.

Railway Signal Association.

Association of Railway Telegraph Superintendents.

National Electric Light Association.

American Electric Railway Engineering Association.

American Institute of Electrical Engineers.

American Electric Railway Association.

American Telephone and Telegraph Company.

United States Bureau of Standards.

Independent Telephone Association of America.

Western Union Telegraph Company.

Postal Telegraph Company.

Mr. Farley Osgood, Newark, N. J., is chairman, and Mr. G. W. Palmer, Jr., Boston, is vice-chairman of the committee. The secretary is Mr. R. D. Coombs, 30 Church Street, New York, and Mr. W. H. Feller, 759 Broad Street, Newark, N. J., is assistant secretary.

Directors' Meeting, New York, January 8, 1915

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, New York, on Friday, January 8, 1915, at 3:30 p.m.

There were present: President P. M. Lincoln, Pittsburgh, Pa., Past-Presidents Ralph D. Mershon and C. O. Mailloux, New York; Vice-President H. H. Barnes, Jr., New York; Managers C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., Bancroft Gherardi and A. S. McAllister, New York; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $8,912.96 was ratified.

The Secretary announced the following additional committee appointments made by President Lincoln since the last meeting:

Use of Electricity in Mines, H. M. Southgate; Industrial Power, A. S. McAllister; Records and Appraisals of Properties, Henry Floy; Protective Apparatus: E. E. F. Creighton, chairman, H. H. Dewey, Louis Elliott, Victor H. Greisser, Ford W. Harris, S. Q. Hayes, Fred L. Hunt, L. E. Imlay, R. P. Jackson, J. T. Lawson, E. B. Merriam, L. C. Nicholson, E. P. Peck, N. L. Pollard, D. W. Roper, O. O. Rider, Charles P. Steinmetz, H. R. Woodrow.

The Board confirmed the appointment by President Lincoln of Mr. Ralph D. Mershon as a member of the Edison Medal Committee to fill the vacancy caused by the resignation of Mr. W. D. Weaver.

Mr. Harry Parker Gibbs was appointed by the Board Local Honorary Secretary for India for the term of two years, to succeed Mr. Clare F. Beames, who recently returned to the United States.

Upon the recommendation of the Meetings and Papers Committee, authority was granted to hold Institute meetings in Cleveland, Ohio, March 18 and 19, and in Pittsburgh, Pa., April 15 and 16, both meetings to be under the auspices of the Industrial Power Committee, with the cooperation of the Cleveland and Pittsburgh Sections respectively.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred one member of the Institute to the grade of Fellow and three to the grade of Member, elected four applicants as Members and 192 as Associates, and ordered the enrolment of 76 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

Upon the petition of Professor S. R. Pritchard, of the Virginia Polytechnic Institute, Blacksburg, Va., the organization of a Student Branch at that Institute was authorized.

Mr. Gano Dunn was unanimously reappointed by the Board as one of the Institute's representatives upon the Board of Trustees of the United Engineering Society, for the term of three years ending on the fourth Thursday of January, 1918.

The Secretary announced that in accordance with Section 21 of the Institute by-laws, President Lincoln would become a member of the John Fritz Medal Board of Award on the third Friday of January, vice Past-President Dugald C. Jackson, whose term would expire on that date.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

Past Institute Meetings

New York.—The 303rd meeting of the Institute was held Friday, January 8, 1915, on the fifth floor of the Engineering Societies Building, beginning at 8:20 p.m. President Paul M. Lincoln presided.

Mr. I. W. Gross presented his paper on *Theoretical Investigation of Electric Transmission Systems under Short-Circuit Conditions.* The discussion was participated in by Messrs. Henry G. Stott, Philip Torchio, Cassius M. Davis, H. R. Woodrow, James Lyman, John B. Taylor, R. W. Atkinson, Charles Fortescue, Hans Lippelt and I. W. Gross.

At the close of the technical session, a smoker was held in the adjoining room.

Past Section Meetings

Baltimore.—November 20, 1914, Physical Laboratory, Johns Hopkins University. Subject: Central Station Design. Paper: "Description of New Boiler House and Turbines at Westport Station," by A. S. Loizeaux. Attendance 32.

December 18, 1914, City Club, Munsey Building. Address by Dr. Charles D. Snyder on "The Human Electro-Cardiogram," illustrated by lantern slides. Attendance 25.

Boston.—December 15, 1914, Auditorium, Engineers Club. Subject: Railway Operation. Paper: "The Electrical System of the Boston Elevated Railway Company," by Paul Winsor. Attendance 100.

Cleveland.—December 21, 1914, Chamber of Commerce. Subject: Electricity in Marine Work. Paper: "Marine Electrical Applications," by H. A. Hornor. Paper was illustrated by lantern slides. Attendance 44.

Detroit-Ann Arbor.—December 11, 1914, Detroit Engineering Society Rooms. Paper: "European Boiler Practise and Boiler Efficiency Meters," by W. A. Blonck. Attendance 140. January 15, 1915, New Engineering Building, University of Michigan. Paper: "Growth of a Modern Utility," by J. D. Gordon, illustrated by moving pictures.

Fort Wayne.—December 17, 1914, Commercial Club. Address by Mr. F. M. Kimball on "The Early History of Electrical Development." Attendance 37.

Indianapolis-Lafayette. — December 11, 1914, Indianapolis. Subject: Electric Furnace. Paper: "The Electric Furnace and the Metallurgy of Iron," by H. A. Schwartz. Attendance 45.

Ithaca.—November 20, 1914, Franklin Hall, Cornell University. Papers: (1) "Edison and the Development of Electric Lighting," by G. A. Rasch; (2) "Determination of Magnetic Flux," by Ralph Brown; (3) "A Novel Slip Meter," by Frederick Bedell. Attendance 45.

December 18, 1914, Franklin Hall, Cornell University. Papers: (1) "Some Stunts," by J. G. Portsch; (2) "Experiments with 70,000 Volts," by I. E. Cole. Attendance 85.

Lynn.—December 14, 1914, Burdett College Hall. Illustrated lecture by Mr. Howard W. DuBois on "Alaska, Our Land of the Midnight Sun." Attendance 410.

January 6, 1915, General Electric Works. Illustrated lecture by Professor D. F. Comstock on "Modern Views of Electricity and Matter." Attendance 262.

Milwaukee.—December 9, 1914. Plankinton House. Illustrated address by Mr. C. G. Sprado on "Allis-Chalmers Oil Engines." Also address by Mr. Francis A. Vaughn on "Milwaukee Street Lighting System." Attendance 125.

January 13, 1915, Plankinton House. Illustrated address by Major H. B. Ferguson, U. S. A., on "Coffer Dam Around the Battleship Maine." Attendance 160.

Panama.—November 22, 1914, Gatun, Canal Zone. Address on "Mechanical and Electrical Features of Floating Cranes," by Henry Schoellhorn, followed by an actual demonstration of a crane in service. Attendance 62.

Philadelphia.—December 14, 1914, Engineers Club. Subject: Telephony. Paper: "Some Experiences with Telephone Grounds and Their Measurement," by L. H. Babbitt. Attendance 85.

December 19, 1914, Engineers Club. Paper: "The Mercury Turbine," by W. L. R. Emmet. Attendance 145.

January 11, 1915, Engineers Club. Paper: "Modern Steel Mill Electrification," by William F. James. Attendance 90.

Pittsburgh.—December 12, 1914. Banquet of Pittsburgh Section, followed by address by President Lincoln and various social features. Attendance 362.

Pittsfield.—December 10, 1914, Masonic Temple. Annual Dance of the Pittsfield Section. Attendance 110.

January 7, 1915, Hotel Wendell. Paper: "Wave Motions," by Professor W. S. Franklin. Attendance 104.

Portland.—January 5, 1915. Paper: "Multiplex Cost and Rate System," by Otto B. Goldman. Joint meeting with local section of N. E. L. A. Attendance 30.

Rochester.—December 18, 1914, Sibley Building. Paper: "Testing for Grounds on D-C. System under Load," by Messrs. Bodler and Lustyk. Attendance 41.

Schenectady.—January 5, 1915, Edison Club Hall. Subject: Illumination. Papers: (1) "Electric Illuminants," by S. H. Blake; (2) "The Arc as a Street Illuminant," by C. A. Halvorson; (3) "Comparison of Different Systems of Operating Series Incandescent Lamps," by H. D. Brown; (4) "Characteristics of Gas-Filled Mazda Lamps," by L. A. Hawkins. Attendance 130.

Seattle.—December 15, 1914, Central Building. Paper: "The Responsibility of the Engineer to the Public," by C. A. Reynolds. Election of officers as follows—chairman, S. C. Lindsay, secretary, E. A. Loew. Attendance 56.

Spokane.—October 16, 1914, Davenport's. Paper: "The Operation of Transmission Lines," by M. W. Birkett.

Report on Detroit Convention by J. B. Fisken.

November 20, 1914, Assembly Hall of Chamber of Commerce Building. Paper: "The Electrical Engineering Course at the Washington State College," by M. K. Akers.

December 18, 1914, Assembly Hall of Chamber of Commerce Building. Papers: "Panama Canal," by D. B. Rushmore, illustrated by lantern slides. "Some Features of the Practical Operation of High-Tension Substations," by Mr. Byron.

Toledo.—January 8, 1915, Toledo Commerce Club. Paper: "Practical Testing of Electrical Apparatus," by E. B. Thurston. Attendance 14.

Urbana.—December 12, 1914, Nelson Hall, Champaign, Ill. Address by Dean C. R. Richards on "Power Transmission," Attendance 174.

Vancouver.—November 12, 1914, Metropolitan Building. Discussion on subject of "Inductive Interference" as legislated upon by State of California. Attendance 16.

December 10, 1914, Metropolitan Building. Paper: "Inductive Interference," by E. P. La Belle. Election of Mr. E. P. LaBelle as Section chairman, to replace Mr. F. D. Nims, who resigned owing to leaving Vancouver. Attendance 16.

Past Branch Meetings

University of Arkansas.—January 11, 1915, Engineering Hall. Papers: (1) "A Hydroelectric Plant," by J. H. Dunn; (2) "Maintaining Railway Electrification," by H. R. Horton; (3) "Sparks," by A. L. Wilson. Attendance 14.

January 13, 1915. Paper: "College Men in Business," by A. L. Mercer. Attendance 37.

Bucknell University.—January 14, 1915, East College. Address by Mr. R. L. Rooke on "Methods Used in Testing Electrical Machinery." Attendance 30.

University of California.—October 21, 1914, Berkeley. Papers: (1) "Water Rights," by H. A. White; (2) "The Dalton Adding Machine," by R. S. Horton. Attendance 14.

November 4, 1914, Berkeley. Papers: (1) "Panama Canal Electrification," by R. D. Andrews: (2) "High-Tension Transmission of Direct-Current Thury System as Used in Europe," by H. A. Mulvaney. Attendance 12.

November 18, 1914, Berkeley. Papers: (1) "The Lead Cell," by A. R. Thompson; (2) "The Edison Cell," by H. D. Miller. Attendance 16.

University of Cincinnati.—January 19, 1915. Illustrated address by Mr. A. C. Perry on (1) "Electric Lighting Systems for Automobiles" and (2) "The Direct Motor Drive for Planers." Attendance 34.

Iowa State College.—January 13, 1915, Ames, Iowa. Lecture by Mr. J. R. Watson on "General Central Station Practise." Attendance 128.

Kansas State Agricultural College.—October 6, 1914, Electrical Lecture Room. Short addresses by Professor Reid and Mr. McNair on the desirability of Institute membership. Attendance 40.

November 6, 1914, Engineering Amphitheatre. Papers: (1) "The History of the A. I. E. E.," by J. S. Hagan; (2) Evolution of Induction Motor and Transformer," by M. P. Goudy; (3) "Live Wires," by L. R. Parkerson; (4) "Electric Starters for Automobiles," by C. A. Hooker. Attendance 55.

December 14, 1914, Electrical Lecture Room. Address by Mr. McNair on "Principles Underlying the Design of the Oscillographs," followed by a demonstration of a new three-element oscillograph. Attendance 42.

Lehigh University.—December 15, 1914, Physics Building. Address by Mr. T. C. Martin on "The N. E. L. A." Experimental lecture by Prof. W. S. Franklin. Attendance 115.

University of Maine.—December 16, 1914, Club Room, Hannibal. Papers: (1) "Modern Applications of Electricity," by Robert F. Thurell, illustrated by lantern slides; (2) "The Civil Engineer's Task in the Construction of an Electric Railway," by Norman Emmons Attendance 24.

Montana State College.—November 20, 1914, Chemistry Building. Illustrated lecture by Mr. W. O. Batchelder on "The Development of the Electrical Manufacturing Industries." Attendance 39.

December 15, 1914, Electrical Building. Address by Mr. J. H. Mills on "The Underwriters Rules, and the National Electrical Code." Attendance 35.

January 12, 1915, Electrical Building. Address by Mr. C. T. Booker on "Experiences in Electrical Work." Attendance 35.

North Carolina College of Agricultural and Mechanical Arts.—January 12, 1915, West Raleigh. Illustrated lecture on "Edison and the Development of Electric Lighting," presented by Messrs. Jeffers, Fontaine, Robinson and Baker. Attendance 18.

Ohio Northern University.—January 13, 1915, Hill Memorial. Address by Mr. W. Parsons on "Electricity in the Mining Industry," followed by paper on "Insulators," by L. W. Brehman. Attendance 26.

Ohio State University.—December 16, 1914, "Union"—Columbus. Banquet, followed by meeting devoted to discussion of Branch affairs. Attendance 26.

University of Oklahoma.—December 16, 1914, Engineering Building. Papers: (1) "Current Topics," by Homer Livergood; (2) "Life of George Westinghouse," by W. Miller Vernor; (3) "Standardization of Direct-Current Machinery," by A. M. Pawnell. Attendance 16.

Pennsylvania State College.—December 2, 1914, Engineering Club Room. Paper: "Effect of Voltage of Different Wave Forms on Life of Tungsten Lamps," by D. L. Markle. Attendance 20.

December 18, 1914, Engineering Building. Paper: "Methods of Remote Control of Motors," by E. C. Woodruff. Attendance 33.

Rhode Island State College.—December 17, 1914, Lippitt Hall. Addresses by L. H. Harris on "High-Tension Transmission," and by Mr. George Slocum on "The Work of the Graduate as an Apprentice." Attendance 26.

Agricultural and Mechanical College of Texas.—December 4, 1914, Electrical Engineering Building. Papers: (1) "Damage to Railways by Flat Wheels," and (2) "Railroad Systems and Freight Rates Throughout the United States." Attendance 162.

December 10, 1914, Assembly Hall. Motion pictures showing the manufacture and uses of electrical machinery, especially the dynamo. Attendance 110.

Throop College of Technology.—December 18, 1914, Accounting Room. Election of officers as follows: chairman, R. S. Ferguson; secretary, W. M. Holmes.

December 18, 1914, Electrical Engineering Lecture Room. Paper: "The Diesel Engine," by C. H. McGuire, illustrated by lantern slides. Attendance 24.

University of Washington.—January 5, 1915, Good Roads Building. Short addresses as follows— (1) "Photometric Tests of the Lighting in the Engineering Building," by Chas. G. Marcy, and (2) "Some Operating Features of the Olympic Power Company's Transmission System," by W. A. Danielson. Attendance 26.

Yale University.—December 11, 1914, New Haven. Subject: Radiotelegraphy. Paper: "Recent Developments in Radiotelegraphy," by J. L. Hogan, Jr. Attendance 122.

Personal

CAV. ING. GUIDO SEMENZA, Local Honorary Secretary of the A. I. E. E. for Italy, has been elected President of the Associazione Elettrotecnica Italiana for the three-year term 1915-1917, thus also becoming President of the Italian

National Committee of the International Electrotechnical Commission.

MR. CARL J. FECHHEIMER, who for nearly five years had charge of the design of alternating-current machinery of the Crocker-Wheeler Company, resigned from that position on November 30th of last year, in order to accept a position in the Power Division of the Engineering Department of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa.

Recommended for Transfer, January 6, 1915

The Board of Examiners, at its regular monthly meeting on January 6, 1915, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO GRADE OF MEMBER

DUDLEY, WRAY, Local Engineer, General Electric Co., Pittsburgh, Pa.

HEHRE, FREDERICK W., Instructor of Electrical Engineering, Columbia University, New York, N. Y.

MACGAHAN, PAUL, Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

MORELAND, EDWARD L., Manager of Boston office, D. C. & W. B. Jackson, Boston, Mass.

PARKHURST, AUSTIN FLINT, Division Supt., Tropical Radio Telegraph Co., New Orleans, La.

POWELL, PERCIVAL HERBERT, Lecturer in Electrical Engineering, Canterbury College, Christchurch, New Zealand.

SHREWSBURY, LEWIS ALFRED, Supt., Electrical Dept., Cia. Minera Las Dos Estrellas, Mexico City, Mexico.

Transferred to the Grade of Fellow January 8, 1915

The following Member was transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on January 8, 1915.

FRIES, JOENS ELIAS, Assistant Engineer, Crocker-Wheeler Co., Ampere, N. J.

Transferred to the Grade of Member January 8, 1915

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on January 8, 1915.

DAWES, CHESTER LAURENS, Instructor in Electrical Engineering, Graduate School of Applied Science, Harvard University, Cambridge, Mass.

TURBAYNE, WILLIAM A., Electrical Engineer, U. S. Light & Heating Co., Niagara Falls, N. Y.

YATES, WILLIAM C., Commercial Engineer, Industrial Control Dept., General Electric Co., Schenectady, N. Y.

Members Elected January 8, 1915

GATES, ALLEN B., Assistant Electrical Engineer, Sanitary District of Chicago; res., 209 N. Lockwood Ave., Chicago, Ill.

GOLDSMITH, ALFRED N., Instructor in Physics, College of the City of New York, New York, N. Y.

QUINN, EDWARD A., General Superintendent, San Joaquin Light & Power Corp., Fresno, Cal.

TAPPAN, CHARLES O., Consulting & Constructing Engineer, 2 Rector St., New York, N. Y.

Associates Elected January 8, 1915

ADAMS, C. C., Chief Electrician, Buhl Malleable Iron Co.; res., 194 Linwood Ave., Detroit, Mich.

*ALLURED, KARL B., 15204 Center Ave., Harvey, Ill.

ANGER, RICHARD E., Instructor, Service Dept., Wagner Electric Mfg. Co.; res., 144 Alexandrine Ave. W., Detroit, Mich.

Arikawa, Aiji, Engineer, Inawashiro Hydro-Electric Power Co., Fukushimaken, Japan.

Ashley, Alfred H., Chief Electrician, Walkerville Light & Power Co., Walkerville, Ont.

Atwell, R. Nelson, Estimate Man, Consolidated Gas, Electric Light & Power Co.; res., 1709 N. Calvert St., Baltimore, Md.

Baddley, Leo W., Assistant Factory Electrical Engineer, Upson Nut Co., Cleveland, Ohio.

*Bardo, Benjamin Franklin, Assistant Engineer, Power Dept., N.Y., N. H. & H. R. R. Co.; res., 24 Everit St., New Haven, Conn.

*Beach, Robin, Instructor in Electrical Engineering, A. & M. College of Texas, College Station, Tex.

*Beckman, F. G., Superintendent of Construction, Arrow Engineering Co., 412 Star Bldg., St. Louis, Mo.

Bell, H. P., Electrical Engineer, San Francisco-Oakland Terminal Rys., 300 Syndicate Bldg., Oakland, Cal.

*Belt, Jefferson Hall, Research Fellow, Engineering Experiment Station, University of Illinois, Urbana, Ill.

Berg, Frank A., Foreman, Electrical & Testing Depts., Richmond Radicator Co., Tacony, Philadelphia, Pa.

Biele, Harry M., Expert (Morkrum Telegraph Printers), Postal Telegraph & Cable Co., 253 Broadway, New York, N. Y.

*Billhimer, Frank M., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 411 Rebecca Ave., Wilkinsburg, Pa.

*Blair, Homer O., Electrical Engineer, with Henry L. Gray, Seattle; res., 524 N. O St., Tacoma, Wash.

Bogardus, Leonard R., Assistant Chief Electrician, Packard Motor Car Co.; res., 575 Fisher Ave., Detroit, Mich.

Bothwell, C. C., Representative, Canadian Laco-Philips Co. Ltd., 249 Victoria St., Toronto, Ont.

Bowers, Frank E., Salesman, A. T. Knowlson Co.; res., 237 Belmont Avenue, Detroit, Mich.

*Brown, Glenn O., Standardization Laboratory Foreman, Kansas City Elec. Light Co.; res., 3000 Woodland Ave., Kansas City, Mo.

Buck, Lucien, Purchasing Engineer, Eastman Kodak Co.; res., 184 Clay Avenue, Rochester, N. Y.

Burgess, David, Master Mechanic & Elec. Engr., Michigan Copper & Brass Co.; res., 389 Campbell Ave., Detroit, Mich.

Byron, J. P., Substation Inspector & Tester, Washington Water Power Co., Spokane, Wash.

Cable, R. J., Chief, Studebaker Plant No. 5; res., 1292 Porter St., Detroit, Mich.

Cardiff, R. L., District Manager, Coast Counties Gas & Electric Co., 173 Pacific Ave., Santa Cruz, Cal.

Carten, James W., Electrical Engineer, Lozier Motor Co.; res., 29 Navarre St., Detroit, Mich.

*Case, Ralph E., Manager, Engineering Dept., R. U. V. Co. Inc., 50 Broad St., New York, N. Y.

Chapman, H. B., Mgr., Industrial and Power Dept., Westinghouse Elec. & Mfg. Co., 1205 Dime Bank Bldg., Detroit, Mich.

Chrysler, W. L., District Superintendent, Washington Water Power Co., Wilbur, Wash.

Clover, G. R., District Manager, Cooper Hewitt Electric Co., 427 Ford Building, Detroit, Mich.

Cone, D. I., Engr. of Transmission Work, Pacific Tel. & Tel. Co., San Francisco; res., 1730 California St., Berkeley, Cal.

*Cook, J. A., On Engineering Staff, D. C. & W. B. Jackson; res., 3210 Arthington St., Chicago, Ill.

Correa, E. J., Salesman, General Electric Co., 124 W. 4th St., Los Angeles, Cal.

*Corte, Anthony, Student Electrical Engineer, General Electric Co.; res., 231 Seward Place, Schenectady, N. Y.

Deininger, Howard F., Electrical Testman, Philadelphia Rapid Transit Co.; res., 2119 Master St., Philadelphia, Pa.

*__Delvin, R. B.__, Electrical Draftsman, Edison Illuminating Co.; res., 421 Second Ave., Detroit, Mich.

*__Doerschuk, Herbert M.__, Assistant Electrical Engineer, Aluminum Company of America, Niagara Falls, N. Y.

Dubsky, Frank, Designing Engineer, General Electric Co.; res., 192 East St., Pittsfield, Mass.

Early, Edward, Electrical Engineer, Moody Engineering Co., 115 Broadway, New York, N. Y.

*__Easler, J. M. T.__, Operator, Pacific Gas & Electric Co.; res., 101 Capistrano Ave., San Francisco, Cal.

Eschler, Richard T., Member of firm, Richter and Eschler, 21 Federal St., Camden, N. J.

*__Etheridge, Harold Lowell__, Inspector, Elec. Dept., N. Y., N. H. & H. R. R. Co., Van Nest; res., 613 W. 145th St., New York, N. Y.

Frank, Leon H., Sales Manager, Mutual Electric & Machine Co., Wheeling, W. Va.

*__Frankel, Mortimer__, District Manager, Roller-Smith Co., 740 Monadnock Block, Chicago, Ill.

*__Geist, Harry Forest__, Development Engineering, Webster Electric Co.; res., 2230 16th St., Racine, Wis.

Georgi, John A., Salesman, A. T. Knowlson Co.; res., 647 Seyburn St., Detroit, Mich.

*__Gilchrest, George Irving__, Research Dept., Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Glunt, S.J., Manager, Electrical Dept. Miller Supply Co., Huntington, W. Va.

Gracey, H. C., Electrician, Chene & Belt Line; res., 296 Melbourne Ave., Detroit, Mich.

Graves, A. G., Commissioner Public Utilities, City of Calgary; res., 314 Scarboro Ave., Calgary, Alta.

Green, Russell E., Representative, Standard Underground Cable Co., The Rookery, Chicago, Ill.

*__Greves, George L.__, Instructor in Electrical Engineering, Case School of Applied Science, Cleveland, Ohio.

Griffiths, W. W., Electrical Engineer, Fort Wayne Electrical Works; res., 3115 South Wayne Ave., Fort Wayne, Ind.

Grimmenstein, Albert W., Switchboard Operator, Power House, Sierra & San Francisco Power Co., Stanislaus, Cal.

Guild, Earle S., Electrical Foreman, Panama Canal, Gatun, C. Z.

*__Gumaer, Percy Wilcox__, Instructor of Electrical Engineering, University of Missouri, Columbia, Mo.

*__Hart, R. Philip__, 2nd, Asst. Instructor, Electrical Laboratory, Sheffield Scientific School, New Haven, Conn.

Hattendorf, H. T., General Foreman, Electrical Construction and Maintenance, Panama Canal, Gatun, C. Z.

Hawkins, H. B., Member of firm, Hawkins-Hamilton Co., Peoples Nat'l Bank Bldg., Lynchburg, Va.

*__Hay, William Oscar, Jr.__, Assistant General Manager, Tug River Power Co., Sprigg, W. Va.

*__Hayes, Daniel William__, Ann Arbor Supt., Eastern Michigan Edison Co., 401 S. Main St., Ann Arbor, Mich.

Hedstrom, E. S., Electrical Engineer, Swedish General Electric Co. Ltd.; res., 56 Phoebe St., Toronto, Ont.

Helm, William A., System Operator, Potomac Electric Power Co.; res., 1014 6th St. N. E., Washington, D. C.

Hertz, S. S., Tester (Electrical), Dynamo Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

*__Hitchcock, Harry W.__, Engineer, American Telephone & Telegraph Co.; res., 102 Convent Ave., New York, N. Y.

Hodge, James, Electrician, Metal Products Co. & Terminal R. R.; res., 692 Commonwealth Ave., Detroit, Mich.

Homrighaus, A. Holle, Sales Manager, Lincoln Electric Co., 619 Free Press Bldg., Detroit, Mich.

***Hull, Robert H.**, Sales Correspondent, Railway & Lighting Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Ingram, Robert T., Operator, Mt. Whitney Power & Electric Co., Hammond, Cal.

Jenks, H. G., Inspector, Charles H. Tenney & Co.; res., 10 Langdon Block, Montpelier, Vt.

***Jennings, C. E.**, Student Engr., Consulting Engg. Dept., General Electric Co.; res., 104 Park Ave., Schenectady, N. Y.

Jennings, Earle B., Wickmire Mining Co., Iron River, Mich.

Keith, Albert, Chief Electrician, Penn Salt Mfg. Co.; res., 117 Poplar St., Wyandotte, Mich.

***Kelso, Newton Thompkins**, Student, Electrical Engineering, Purdue University; res., 215 Lutz Ave., W. Lafayette, Ind.

***Kiehl, Eugene P.**, Electrical Engineer, Atlantic Refining Co.; res., Chelten Ave. & 13th St., Philadelphia, Pa.

Kilcoyne, F. R., Sales Engineer, Commercial Electrical Supply Co., 47 Park Place, Detroit, Mich.

Killam, Leslie, Plant Superintendent, Wisconsin Telephone Co., 183 Fifth St., Milwaukee, Wis.

Kramer, H. A., Draftsman, Panama-Pacific International Exposition Co.; res., 4029 23rd St., San Francisco, Cal.

Laird, Kenneth V., Graduate Student, University of California; res., 105 Parkside Drive, Berkeley, Cal.

Lakin, Charles, Chief Electrician, Kelsey Wheel Co.; res., 69 Maplewood Ave., Detroit, Mich.

Lamb, Gilbert C., Electrical and Structural Draughtsman, Connecticut River Transmission Co., Worces ter, Mass.

Lamb, Irving C., General Electric Co.; res., 243 No Menard Ave., Chicago, Ill.

***Lassaff, Benjamin W.**, 80 St. James Ave., Boston, Mass.

Linse, Rudolf, Electrical Superintendent, Power Station, Elektricitetsverket, Malmo, Sweden.

Lockert, Wilbur H., Assistant Engineer, Line Dept., Northern Ohio Traction & Light Co.; res., 88 Vesper St., Akron, O.

***Loebenstein, Julian**, Junior Elec. Engr., Public Service Commission, 1st Dist.; res. 67 E. 84th St., New York, N. Y.

Lowry, Ernest A., Chief Clerk, Electric Dept., Board of Light and Heat Commission; res., 17 McTague St., Guelph, Ontario

Luster, Eric W., Cadet Engineer, Public Service Electric Co.; res., 943 N. Broad St., Elizabeth, N. J.

Lustyk, Frank John, Electric Testing Dept., Eastman Kodak Co.; res., 43 Kosciusko St., Rochester, N. Y.

Lytle, Bruce H., Electrical Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Mackay, Robert, Superintendent, Electric Light Department, City Hall, Calgary, Alta.

***Markland, Albert R.**, Special Apprentice, Pennsylvania Railroad Co.; res., 2211 Broad Ave., Altoona, Pa.

Marsh, J. D., Testing and Research, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 724 Kelly St., Wilkinsburg, Pa.

***Marx, Roland G.**, Student, Stanford University; res., 357 Kingsley Ave., Palo Alto, Cal.

***Mavity, Victor T.**, Assistant Superintendent, Electrical Dept., Rosario Mines, San Juancito, Honduras, C. A.

***Mayer, Edwin C.**, Instructor in Physics, Cornell University; res., 202 E. Buffalo St., Ithaca, N. Y.

***Mayforth, John Henry**, Maintenance Engineer, Eisemann Magneto Co., Brooklyn; res., Glen Cove, N. Y.

McCall, James F., Mechanical Supt. and Chief Engineer, Calgary Municipal Power Department, City Hall, Calgary, Alta.

McEvoy, Walter, Engineer, with Walter Kidde, 140 Cedar St., New York, N. Y.; res., Keyport, N. J.

McNally, John H., Smoke Inspector, Philadelphia Bureau of Boiler Inspection, 305 City Hall, Philadelphia, Pa.

McNaughton, John R., Treasurer, McNaughton-McKay Electric Co.; res., 147 Atkinson Ave., Detroit, Mich.

***Mehl, Bernhard Martin**, Meter Dept., Pacific Gas & Electric Co., 1314 29th St., Sacramento, Cal.

Michetti, Octavio D., Lieutenant Engineer, Argentine Navy; res., Agrelo 3623, Buenos Aires, Argentine Republic, S. A.

Mixson, Archibald M., Electrician, Charleston Consolidated Ry. & Lighting Co.; res., 23 Wall St., Charleston, S. C.

Moody, Morris R., General Inspector, Portland Eugene & Eastern Ry. Co.; res., 644 Everett St., Portland, Ore.

Moore, W. W., Chief Electrician, American Car & Foundry Co.; res., 23 Pacific Ave., Detroit, Mich.

***Morgan, Fred**, Resident Engineer, with Gardiner S. Williams; res., 417 Thompson St., Ann Arbor, Mich.

***Morningstar, B. Franklin**, Engr., Steam Dept., Cleveland Elec. Illuminating Co.; res., 2200 Prospect Ave., Cleveland, O.

Morrow, R. B., Electrical Engineer, Waneta Development Co., Ltd., 720 Paulsen Bldg., Spokane, Wash.

Mortensen, M. T., Chief Electrician, Michigan Steel Casting Co.; res., 801 Dickerson Ave., Detroit, Mich.

***Moulton, V. C.**, Commercial Engineer, I. & P. Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

***Murphy, Edward S.**, Engineer, Wagner Electric Mfg. Co.; res., 333 Van Dyke Ave., Detroit, Mich.

Murphy, Eugene B., Assistant Radio Engineer, Federal Telegraph Co., San Francisco; res. Burlingame, Cal.

Murphy, W. V., Construction Foreman, General Electric Co., Tallulah Falls, Ga.

Notley, George, Electrical Inspector, City of Calgary Inspection Department; res., 306 14th Ave. E., Calgary, Alta.

Nowaske, G. W., Electrician; res., 973 Forest Ave. East, Detroit, Mich.

Olson, R. F., Load Dispatcher, Portland Railway, Light & Power Co.; res., 6903 59th Ave. S. E., Portland, Ore.

Orcutt, Guy H., Electrical Engineer, Michigan Alkali Co.; res., 74 Van Alstyne Blvd., Wyandotte, Mich.

***Pashek, Albert L.**, Electrical Inventory Work, D. C. & W. B. Jackson, Boston, Mass.

Payette, Philip L., Chief Electrician, Michigan Alkali Co.; res., 247 Second St., Wyandotte, Mich.

Payne, Robert T., Lock Operator, Gatun Locks, Panama Canal, Gatun, C. Z.

Peck, D. L., Manager, Service Dept., A. T. Knowlson Co., 99 Congress St. East, Detroit, Mich.

Penniman, A. L., Jr., Acting Supt., Steam Stations, Consolidated Gas, Electric Light & Power Co., Westport, Md.

Perkins, Harry S., District Manager, Elec. Ry. Improvement Co. of Cleveland, 47 Park Place, Detroit, Mich.

Peterson, Carl J., Superintendent, Hydro-Electric Plants, Apple River Power Co., Somerset, Wis.

Plasko, John G., Electrical Engineer, Parke Davis & Co.; res., 395 Mt. Clair Ave., Detroit, Mich.

***Popp, C. M.**, Cost & Estimating, General Electric Co.; res., 24 Baker St., Lynn, Mass.

Powers, Walter Palmer, Instructor of Electrical Engineering, University of Pittsburgh, Pittsburgh, Pa.

***Prior, Allen A.**, Research Assistant, Massachusetts Institute of Technology, Pierce Hall, Cambridge, Mass.

Purdy, Harry, Chief Electrician, Continental Motor Mfg. Co.; res., 36 Coplin Ave., Detroit, Mich.

***Pye, H. N.**, Assistant Professor of Engineering, Newberry College, Newberry, S. C.

Pyle, L. N., District Manager, Westinghouse Lamp Co., 1215 Dime Bank Building, Detroit, Mich.

RamSami, S. M., Vema Lodge, Mallaswaram, Bangalore, India.

***Raney**, E. C., General Manager, Automatic Reclosing Circuit Breaker Co., Columbus; res., Reynoldsburg, O.

Rath, A. J., Asst. Chief Electrician, Packard Motor Car Co.; res., 570 Fisher Ave., Detroit, Mich.

***Ready, Lester** S., Asst. Electrical Engineer, California Railroad Commission, 833 Market St., San Francisco, Cal.

Reger, Herbert H., Lock Operator, Panama Canal, Gatun, C. Z.

Richards, William A., Construction Supt., McNaughton McKay Electric Co., Windsor; res.. Walkerville, Ont.

Rich, B. C., Assistant Chief Electrician, Dodge Brothers; res., 946 Bellevue Ave., Detroit, Mich.

Rickwood, Harold Archibald, Electrical Engineer, Pirelli General Cable Works Ltd., Southampton, England.

Roach, Arthur E., Sales Engr., McNaughton-McKay Elec. Co., Windsor, Ont.; res., 175 Westminster Ave., Detroit, Mich.

Robinson, E. W., Chief Electrician, Ford Motor Co. of Canada, Walkerville, Ont.; res., 968 12th St., Detroit, Mich.

Robinson, Gordon L., Chief Electrician, Studebaker Corp., Plant No. 1; res., 189 Hazelwood Ave., Detroit, Mich.

***Rommel, William** C., Elec. Inspector, Electrical Bureau of Philadelphia; res., 1916 Montgomery Ave., Philadelphia, Pa.

***Rothmaler, Oswald**, Junior Ry. Engr., Public Service Commission, New York; res., 1293 Bergen St., Brooklyn, N. Y.

Royer, J. E. E., Operating Engineer, Washington Water Power Co., Spokane, Wash.

Rudolph, J. M., Superintendent, Police Control, City of Calgary Light Department, Calgary, Alta.

Ruetschi, Herm. Ad., Local Manager, Central Iowa Light & Power Co., 609 Central Ave., Ft. Dodge, Iowa.

Rutter, A. A., Salesman, Wagner Electric Mfg. Co., 1253 Woodward Ave., Detroit, Mich.

***Samuels, Irving**, Engineer of Distribution, Lehigh Valley Light & Power Co., 542 Hamilton St., Allentown, Pa.

***Saunders, Harry** O., Toll Plant Engineer, Illinois Division, Central Union Tel. Co., Reisch Bldg., Springfield, Ill.

***Savant**, D. P., Transformer Engineer, Duncan Elec. Mfg. Co., Lafayette, Indiana.

Seguin, Louis Z., Chief Electrician, American Blower Co.; res., 81 Pollard St., Detroit, Mich.

Shaw, H. J., Sales Engineer, W. G. A. Reid Co., 17 Washington Blvd., Detroit, Mich.

Shaw, Francis Robert, Switchboard Operator, Public Service Electric Co.; res., 32 Bank Place, Plainfield, N. J.

Sirnit, J. A., Electrical Engineer, Alabama Power Co., 940 Brown-Marx Bldg., Birmingham, Ala.

Smith, John R., Consulting Engineer, Doyle & Patterson; res., 732 Sherwood Drive, Portland, Ore.

***Snow, Wilber** R., Pacific Gas & Electric Co., Napa, Cal.

Spaulding, J. G., Electrical Contractor, 248 Michigan Ave.; res., 814 Ferry Park Ave., Detroit, Mich.

***Shaper, Samuel** R., Electrical Draftsman, with Charles T. Main, First National Bank Bldg., Great Falls, Mont.

Steed, Richard L., Erecting Engineer; res., 1593 Canton Ave., Detroit, Mich.

***Steeper**, T. P., Electrical Engineer, Trumball Public Service Co., Electric Block, Warren, Ohio.

Steinmetz, Fred E., Dept. Foreman Electrician, Anderson Elec. Car Co.; res., 461 Wabash Ave., Detroit, Mich.

***Stemmons, Beverly** L., Assistant Consulting Engineer, General Electric Co.; res., 332 Paige St., Schenectady, N. Y.

Stevens, Charles T., Electrician, Hupp Motor Co., Detroit; res., 19 James St. E., River Rouge, Mich.

***Stiner, H. Wray**, Section Head of Transformer Test, General Electric Co.; res., 68 Burbank St., Pittsfield, Mass.

***Stottler, Malcolm Warren**, Apprentice, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Sutherland, Wm. J. K., Electric Foreman, Rochester Railway & Light Co., Station No. 3, Rochester, N. Y.

***Taylor, Richard Salmon**, Engineering Assistant, Engineering Dept., New York Telephone Co., 15 Dey St., New York, N. Y.

Ten Brook, Richard W., Electrician, 168 Kenelworth Ave., Detroit, Mich.

Terry, Charles W., Manager, Detroit Office, Electric Storage Battery Co., 722 Ford Bldg., Detroit, Mich.

Tiemann, William O., Superintendent, John D. Templeton Co.; res., 9 David St., Detroit, Mich.

***Tripple, George**, Industrial and Power Sales Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

***Turner, Floyd F.**, Meter Dept., Carolina Power & Light Co., Raleigh, N. C.

Turner, Waldso, Vice-President, Iron City Engineering Co., 1115 Dime Bank Bldg., Detroit, Mich.

***Vidro, Edward F.**, Representative, Electrical Controller & Mfg. Co., Cleveland, O.; res., 363½ McClellan Ave., Detroit, Mich.

Voorhess, Charles R., In charge of hydro-electrical work, Henry Ford Farms, Dearborn, Mich.

Walthall, O. A., District Agent, San Joaquin Light & Power Corp., McFarland, Cal.

***Warner, Russell A.**, In charge of testing electrical machinery, General Electric Co., Schenectady, N. Y.

***Weil, Mahlon S.**, Cadet Engineer, Operating Dept. (Elect.), Northern Indiana Gas & Electric Co., Hammond, Ind.

White, Daryl Elliot, Salesman, Ry. & Lighting Dept., Westinghouse Elec. & Mfg. Co., Alaska Bldg., Seattle, Wash.

White, L. R., Asst. Elec. Engr., Chicago Association of Commerce, 1333 Peoples Gas Bldg., Chicago, Ill.

***Wilcox, Leslie William**, Apprentice, St. Paul Gas Light Co.; res., 115 W. Robie St., St. Paul, Minn.

***Wilkinson, Kenneth L.**, Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

Williams, E. H., Electrical Construction Foreman, Southern Sierras Power Co., Riverside; res., Halleck, Cal.

Wilsher, Ernest Henry, Chief Electrician, Dodge Brothers; res., 1420 Brush St., Detroit, Mich.

***Wines, Harold D.**, Instructor in Electrical Engineering, University of Michigan, Ann Arbor, Mich.

Wise, C. E., District Manager, Cutter Electrical and Mfg. Co., 427 Ford Bldg., Detroit, Mich.

Yeager, Weldy S., Foreman, Stanislaus Power House, S. & S. F. Pr. Co., Stanislaus, Cal.

***Yerkes, Earle P.**, Specification Writer, Bell Telephone Co. of Penna., 11th & Filbert Sts., Philadelphia, Pa.

Yorke, Layton Park, Wiring Inspector, City Electric Light Dept., Edmonton, Alberta.

Young, C. A., System Operator, Washington Water Power Co.; res., 2027 Mansfield Ave., Spokane, Wash.

*Former enrolled Students.

Total 192

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1915.

Aime, F. L., Pittsburgh, Pa.

Arnold, F. J., Chicago, Ill.

Axell, C. G., Chicago, Ill.
Baker, J. S., Chicago, Ill.
Baugher, E. J., Wheeling, W. Va.
Berg, L., Minneapolis, Minn.
Bigelow, C. H., Millville, N. J.
Blake, A. D., New York, N. Y.
Boggs, C. E., Summerville, Ore.
Booth, J. B., Norfolk, Va.
Brown, J. W., E. Pittsburgh, Pa.
Brown, R. S., Redding, Cal.
Browning, G. J., Wappingers Falls, N.Y.
Brumhall, J. H., Boone, Ia.
Bryan, H. C., Ft. Wayne, Ind.
Burleigh, A. C., Leetsdale, Pa.
Burnett, J. L., Ft. Wayne, Ind.
Cadwallader, J. A., Philadelphia, Pa.
Campbell, E. E., Chicago, Ill.
Clement, L. M., Kahuku, T. H.
Coup, F. T., Chicago, Ill.
Creecy, C. E., Baltimore, Md.
Crowe, J. W., Baker, Ore.
Curtis, A. M., New York, N. Y.
Curtis, M., Butte, Mont.
Dallis, P. A. (Member), Atlanta, Ga.
Dalton, W. J., Detroit, Mich.
Daly, R. J., Philadelphia, Pa.
Douglass, F. S., Indianapolis, Ind.
Falloon, E. J., Salt Lake City, Utah.
Fitzgerald, T. W., Tucson, Ariz.
Fish, J. A., Gadsden, Ala.
Frankenberry, T. H., Raleigh, N. C.
Freygang, W.H., Long Island City, N.Y.
Garrett, A. M., Chicago, Ill.
Goebel, R. C., Minneapolis, Minn.
Gordon, C. S., San Antonio, Tex.
Hale, B. K., Columbus, Ohio.
Haraguchi, T., Schenectady, N. Y.
Harrington, C. A., Youngstown, O.
Harth, L., Lac du Bonnet, Man.
Hatcher, C. K., Snoqualmie Falls, Wash.
Herault, P. C., Lindale, Ga.
Heybrock, E., Chuquicamata, Chile
Hirsch, G. (Fellow), Columbus, O.
Hoxie, C. A., Schenectady, N. Y.
Isaacs, W. F., Lawrence, Mass.
Jinguji, G., Schenectady, N. Y.
Johnston, V. G., Morganton, N. C.
Josselyn, B. S., Jr., Chicago, Ill.
Kessler, R., Hartford, Conn.
Kimbell, C. L., Philadelphia, Pa.
Klippel, W. P., Ft. Wayne, Ind.
Koppel, J. G., Saulte Ste. Marie, Mich.
Langley, G.R.(Member), Peterboro, Ont.
Lee, C. M., New York, N. Y.
Loewenstein, L.C. (Fellow), Lynn, Mass.
Lougee, N. A., Schenectady, N. Y.
Lowry, H. K., Chicago, Ill.
Lush, A., Canterbury, N. Z.
MacIntosh, R. J., Atlanta, Ga.
Mackay, W. C., Anaconda, Mont.
Meston, A. F., New York, N. Y.
Meyers, J. F., Chicago, Ill.
Monkhouse, A., Moscow, Russia.
Moore, E. T. (Member), Syracuse, N.Y.
Moore, W. J., Lockport, Ill.
Morrison, D. P., Pittsburgh, Pa.
Nicholson, C. L., Toronto, Ont.
Olson, M. C., Schenectady, N. Y.
O'Neal, J. P., E. Pittsburgh, Pa.
Ottmer, H. G., Ann Arbor, Mich.
Paulsel, F. F., Noblesville, Ind.
Pontecorvo, L. (Member), Vado, Italy.
Press, E. E., Johannesburg, S. A.
Ransdall, R. A., San Francisco, Cal.
Read, E. K., E. Pittsburgh, Pa.
Richardson, H. J., Chicago, Ill.
Rous, C. C., Toronto, Ont.
Sanborn, G. M., New York, N. Y.
Semmes, L. D., Madison, Ark.
Skidmore, E. W., Lawrenceburg, Tenn.
Slater, J. H., Emeryville, Cal.
Stahl, C. R., Stotesbury, W. Va.
Stevenson, E. E., Los Angeles, Cal.
Sticht, A. E. J., Troy, N. Y.
Straw, J. B., Philadelphia, Pa.
Sutil, R. E., Santiago, Chile.
Sykes, C. S., Philadelphia, Pa.
Tuttle, R. E., Springfield, Mass.
Walters, J. N., New York, N. Y.
Walton, J. N., Pittsfield, Mass.
Wilder, H. C., Malone, N. Y.
Williams, L. C., San Francisco, Cal.
Williamson, A. G., Pittsburgh, Pa.
Williamson, B. A., Los Angeles, Cal.
Wood, D. C., Chicago, Ill.
Yates, J. E., Portland, Ore.
Total 98.

Students Enrolled January 8, 1915

7029 Mori, N. R., Univ. of Washington.
7030 Bracken, J. L., Yale University.
7031 Schlotzhauer, H.A., Jr., Yale Univ.
7032 Haines, K. B., Yale University.
7033 Slade, H. L., Jr., Yale University.

7034 Schuler, L. L., Lewis Institute.
7035 Schmidt, R.L., Univ. of Rochester.
7036 Tafel, R. E., Purdue University.
7037 Jacoby, A. B., Purdue University.
7038 Coffin, A. A., Univ. of Alabama.
7039 Browning, S. D., Univ. of Calif.
7040 Daw, A. H., Colorado College.
7041 Smith, E. B., Washington St. Coll.
7042 Wieseman, R. W., Lehigh Univ.
7043 Fuller, C. W., Univ. of Rochester.
7044 Vitzthum, H. L., Lehigh Univ.
7045 Bunker, F. L., Clemson College.
7046 Benjamin, R. N., Clemson College
7047 Ward, J., Clemson College.
7048 Berly, G. E., Clemson College.
7049 Bennett, C. G., Clemson College.
7050 Stewart, R. B., Clemson College.
7051 Barnett, M. S., Clemson College.
7052 Edmonds, M., Clemson College.
7053 Burnett, G. N., Clemson College.
7054 Blake, W. E., Clemson College.
7055 Buyck, D. D., Jr., Clemson Coll.
7056 Jackson, O. E., Univ. of Minn.
7057 Garvey, W. S., Univ. of Minn.
7058 Adler, E. H., Univ. of Minn.
7059 Robertson, B. J., Univ. of Minn.
7060 Johnson, E. W., Univ. of Minn.
7061 Jones. G. R., Univ. of Minn.
7062 Dunham, R. O., Univ. of Minn.
7063 Elliott, A. D., Univ. of Minn.
7064 Johnson, C. J., Univ. of Minn.
7065 Harris, H. R., Univ. of Minn.
7066 Shaver, J. H., Pratt Institute.
7067 Gliddon, G. H., Univ. of Roch.
7068 March, S. A., Lewis Institute.
7069 Heston, A. O., Okla. A. & M. Coll.
7070 Lewis, C. W., Okla. A. & M. Coll.
7071 Wright, H.M., Okla. A. & M. Coll.
7072 Corbin, B. O., Okla. A. & M. Coll.
7073 Mayo, H. J., Univ. of California.
7074 Jain, R. S., Univ. of Illinois.
7075 Munson, C. H., Univ. of Roch.
7076 Hervey, W. K., Kans. St. A. Coll.
7077 Raub, E. S., Carnegie Inst. Tech.
7078 Moore, A.D., Carnegie Inst. Tech.
7079 Adolfzen,S.W.,CarnegieInst.Tech.
7080 Gumbart,H.E.,CarnegieInst.Tech.
7081 Wildberg,L.K.,CarnegieInst.Tech.
7082 Tilbrook,G.L.,Carnegie Inst.Tech.
7083 Forty, F. A., Univ. of Illinois.
7084 Wuichet, R. P., Ohio St. Univ.
7085 Swigart, J. K., Ohio St. Univ.
7086 Anglemyer, W. J., Ohio St. Univ.
7087 Siek, H. G., Ohio State Univ.
7088 Pavey, C. C., Ohio State Univ.
7089 Wade, H. R., Univ. of Kansas.
7090 Ward, A. L., Univ. of Toronto.
7091 Dupuy, A. E., Colo. St. Agri. Coll.
7092 Leith, R. E., Univ. of Washington.
7093 Yoshioka, M., Univ. of Wash.
7094 Moore, C. E., Tufts College.
7095 Hess, A. F., Lehigh University.
7096 Markowitz, J., Yale University.
7097 Fittz, R. U., Tufts College.
7098 Tinch, H. H., Univ. of Pittsburgh.
7099 Wassuman, M. S., Univ. of Pitts.
7100 Barrer, G. A., Armour Inst. Tech.
7101 Elliott, V. D., Throop College.
7102 Balmford, J. A., Columbia Univ.
7103 Failla, G., Columbia University.
7104 Frey, E. R., Lehigh Univ.
Total 76.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than 50 words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Vacancies

V-57. District representative wanted in one of the large Middle West cities to handle steam turbine account. Applicant must have had experience in steam engineering practise, and the application of turbines, turbo-pump sets, turbo-generator sets and turbo-blower sets, and the sales ability necessary to the successful handling of the account.

Men Available

180. Electrical Engineer. University training, age 28. Six years construction work, transmission lines and power-house equipment; three years superintendent with mining company using d-c. and storage battery locomotives for haulage, and a-c. motors for hoists. Would like similar position with mining company. Distance no object.

181. Technical graduate desires position with public utilities company as sales manager or power salesman. Has recognized ability and established reputation in this line of work. Thoroughly familiar with cost of power and uses of central station service in all branches of the industry. Location East or South preferred.

182. Electrical-Mechanical Engineer. Age 32. Twelve years practical experience in charge of construction, operation and maintenance of steam and hydroelectric power plants, high-tension systems, machinery shops, aerial tramways, all classes mining and milling machinery repairs. Speak Spanish. Desire position in charge of electrical, mechanical or construction work. Will go anywhere.

183. Draftsman, with fifteen years experience in the design of direct- and alternating-current machines. Engaged at present desire change.

184. Electrical Engineer. Graduate 1914; with shop experience. Desires position with reliable manufacturing or commercial firm. Salary no object.

185. Electrical Engineer. Age 27. Five years varied experience with manufacturing and power companies. Desires opportunity in engineering or construction with contracting or power company; capable of taking charge of medium-size system. Good draftsman. At present employed as construction foreman for large company. At liberty May 1.

186. Superintendent of Construction. Specialist in installing hydroelectric equipment. Twenty years' experience; fifteen years in Latin-American countries. Capable of taking charge of installation of power-house machinery, substation and transmission line work. Speak Spanish. Preference southern countries.

187. Electrical Engineer. Graduate of Univ. of Michigan, 1914. Age 27. Now teaching in an engineering college. Desires position with electric railway or in electrical department of steam railway.

188. Electrical Engineer, Univ. of Wisconsin, 1908, B. S. E. E. One year electrical inspection, two years General Electric test, four years in charge of 25,000-kw. hydro-electric station. Desires position with electrified steam road, large interurban system, or power company. Married and now employed, but can leave on short notice.

189. Designing Engineer, technical graduate, desires position. Eleven years experience covering generation, transmission and application of electric power with manufacturing, electric railway, power and irrigation companies and consulting engineering firm. Member A. I. E. E.

190. Electrical Engineer, technical graduate. Three years' experience in charge of testing laboratory of large light and power company, general engineering, drafting, estimating, in-

ventory and appraisal work with gas and electric company; isolated plant experience. Prefer position with traction company in Middle West, but will consider anything. Salary very moderate.

191. Electrical Engineer, technical graduate. Fifteen years practise, principally as manager and superintendent of electric departments of large steel, copper and cement companies. At present employed; leave on reasonable notice. Good salary expected. Member A. I. E. E., Assoc. Mem. A. S. C. E.

192. Engineer. Electrical graduate with six years experience designing and constructing electrical distributing apparatus, wiring, inspection of installations, operation of all types of electrical machinery. Age, 29. Middle West preferred.

193. Superintendent and Engineer. Technical education; age 40; married. Superintendent and engineer for large telephone company for twelve years. Electric light plant experience and some factory, as well as sales experience. Especially capable of handling men on construction and maintenance work to economically produce results. Temperate and absolutely reliable.

194. Electrical Engineer. Young man, technical graduate, with seven months drafting and three and a half years commercial experience, is seeking position, in commercial department preferred. Has held responsible position.

195. Electrical Engineer. Graduate western university 1912. Desires position where experience in different classes of work may be obtained. Valuation experience; electrician on hydro-electric construction; operating hydroelectric plant. At present employed.

196. Electrical-Mechanical Engineer. Graduate; age 30. Ten years' experience covering drafting, layout of all types of plants, installation. Past three years superintendent for electrical contracting firm, estimating and installing. Wide experience in motors and generators. Prefer position in Canada.

197. Electrical Engineer. Graduate; age 27; married. Two years' experience with a-c. and d-c. motors in manufacturing, testing, drafting and office work. At present employed designing automatic machinery.

198. Electrical Engineer. Technical education; age 28. Desires connection with central station company in commercial department or as salesman with manufacturer. Several years' experience. Year and a half with Chicago Edison Co. in commercial dept. Familiar with estimates, rates, reports, illumination, etc. Possesses executive ability. Energetic and of good personality.

199. Electrical Engineer. Technical education; age 26. Three years' experience in design, construction and operation of power plants, substations and transmission lines; two and a half years' experience on steam railway electrification project in calculation of electric energy requirements and design of transmission lines, substations, power houses and determination of other requirements.

200. Electrical Engineer. Technical graduate; age 32. Ten years' experience in operation, design and construction of power plants and transmission systems. Three and a half years chief draftsman large hydroelectric development on Pacific Coast. Desires position as office or field engineer, or superintendent light and power company.

201. Technical Graduate Age 27. Two years testing engineer, three years station construction and engineering work for electric traction and light company. Experienced in planning new and repair work. Desires position with construction or operating company.

202. Electrical Engineer, married, graduate of Eastern University. Has had 10 years' experience testing electrical apparatus for the market, also $2\frac{1}{2}$ years in experimental laboratory. Prefers Eastern location with consulting or designing engineer, but is open to any reasonable offer. Best of reference furnished; can accept position at once.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Gas Light Journal vol. 1; vol. 2, nos. 13-14, 16-36; vol. 3, nos. 37-53, 56-60. New York, 1859-62. (Purchase.)

On the Convection of Heat from Small Cylinders in a stream of fluid: determination of the convection constants of small platinum wires with applications to hot-wire anemometry. By L. V. King. (From Philosophical Transactions of the Royal Society of London. Ser. A., vol. 214, p. 373-432.) (Gift of author.)

Electric Traction Weekly. vol. 2, nos. 25-29; vol. 3, nos. 2-3, 6-10, 12, 15; vol. 6, nos. 3, 19. Cleveland, 1906-07, 1910. (Purchase.)

Electrical Age. vol. 4, nos. 1-3, 6-24; vol. 5, nos. 1-5, 7-24; vol. 12, nos. 1, 3, 5-6; vol. 15, nos. 7, 14; vol. 23, nos. 21-23; vol. 24, no. 27; vol. 25, no. 13; vol. 27, no. 18. New York, 1886-88, 1893, 1895, 1899, 1900, 1901. (Purchase.)

Electrical Record. vol. 3, no. 6. New York, 1908. (Purchase.)

Die elektrische Kraftübertragung. By Herbert Kyser. Berlin, 1914. (Purchase.)

Field Practice, an Inspection Manual for Property Owners, Fire Departments and Inspection Officers. Boston, National Fire Protection Association, 1914. (Gift of Publishers.) Price $1.50.

If it is true as has been stated recently, that the fire losses in the United States have been great enough to more than pay for the Panama Canal, all attempts to prevent this alarming waste should be welcomed. Successful fire prevention is almost entirely dependent on adequate inspection. This official handbook summarizes in the most practical way the practice of inspection. It treats of fire hazards, and of fire protection, including automatic sprinkler installations. Its handy pocket form and good index add to its value as a working tool. W. P. C.

Industrial Arts Index, 1914. White Plains, N. Y., 1914. (Exchange.)

International Catalogue of Scientific Literature. 12th Annual Issue. A—Mathematics; C—Physics, London, 1914. (Gift of E.D. Adams)

Journal de Chimie. Physique. vol. 3, Geneve, 1905. (Purchase.)

Journal Telegraphique. vol. 24, nos. 2-12. Berne, 1900. (Purchase.)

Mechanical Design and Construction of Generators. By R. Livingston. London, 1914. (Purchase.)

Municipal Journal & Engineer. (Formerly City Government.) vol. 2, 3, 5, 6; vols. 10, nos. 1, 4-5. New York, 1896-7, 1898-99, 1901. (Purchase.)

National Electric Light Association. New England Section. Proceedings. 1909-10, 1910-11. Boston, 1910-11. (Purchase.)

Progressive Age. vol. 2, Phil., 1884. (Purchase.)

Public service. vol. 10, nos. 1-2; vol. 11, no. 4; vol. 12, no. 6; vol. 13; vol. 14, nos. 1-3. Chicago, 1911-1913. (Purchase.)

Revue Internationale de l'Electricité. Year 1, nos. 1-4; Year 2, no. 10; Year 3, nos. 25, 36; Year 4, no. 50. Paris, 1885-1888. (Purchase.)

Royal Institution of Great Britain. Quarterly Journal of Science. vols. 13, 24-27, 29. London, 1822, 1827-30. (Purchase.)

Royal Society of Edinburgh. Proceedings vols. 12-14, vol. 16, p. 693-772; vol. 22. Edinburgh, 1884-88, 1900. (Purchase.)

Société Belge d'Electriciens. vol. 1, nos. 1, 3, 4; vol. 2, nos. 1-3, 5-10; vol. 3, nos. 2-5, 7, 10. Bruxelles, 1884-86. (Purchase.)

Society of Arts. Journal. vol. 32, London, 1884. (Purchase.)

Society of Chemical Industry. Proceedings of First General Meeting, 1881. Manchester, 1881. (Purchase.)

Society of Engineers in the University of Minnesota. Yearbook 1892-93, 1893-94. Minneapolis, 1893, 1895. (Purchase.)

La Soudure Electrothermique. By Jean Escard. n.p. n.d. (Purchase.)

Southern Electrician vol. 6, nos. 2-3. Charlotte, N. C., 1908. (Purchase.)

Southwestern Electrical & Gas Association. Annual Convention 9th, 1913. (Exchange.)

Street Railway Journal vols. 1-4; vol. 6, no. 6. New York, 1884-88, 1890. (Purchase.)

Street Railway Review. vol. 16, no. 5. Chicago, 1906. (Purchase.)

Telephony. vol. 19, nos. 1-3, 5-11, 13-15, 17-18. Chicago, 1910. (Purchase.)

U. S. Interstate Commerce Commission. Annual Report 28th, 1914. Washington, 1914. (Exchange.)

Verband Deutscher Elektrotechniker. Mitglieder-Verzeichnis Aug. 1914. n.p. (Gift of Verband Deutscher Elektrotechniker.)

——Bericht uber die Jahresversammlung, May 26, 27, 1914. Berlin, 1914. (Gift of Verband Deutscher Elektrotechniker.)

Yale Scientific Monthly. vol. 3, nos. 3, 7; vol. 6, nos. 4-7, 9; vol. 7, nos. 3-4, 6-9; vol. 8, nos. 1, 3, 5-9. New Haven, 1896-97, 1900-02. (Purchase.)

TRADE CATALOGUES

Goldschmidt Thermit Co. New York City. Reactions. vol. 7, no. 4, 1914.

Bierman-Everett Foundry Co.. Newark, N. J. Fountain boxes and conduit fittings for the electrical trades. 1914.

Archbold-Brady Co. Syracuse, N. Y. Steel transmission structures and catenary bridges. 32 pp. 1914.

General Electric Co. Schenectady, N. Y. Bull. no. 45602. Lightning arresters for series lighting circuits. Dec. 1914.

——G-E. Electric fans. 19 pp. 1915.

Philadelphia Electric Co. Philadelphia, Pa. Bulletin. Dec. 1914.

Western Electric Co. New York City. Electrical Supply Year Book. 1915. 24+ 1216 pp.

UNITED ENGINEERING SOCIETY

Architectural Pottery. By Leon Lefevre, translated from the French by K. H. Bird, and W. M. Binns. London, 1900. (Purchase.)

Bibliographie der Deutschen Zeitschriften Literatur. Beilage band VI. Band XXIV A. Leipzig, 1914. (Purchase.)

Bone Products and Manures. By Thomas Lambert. London, 1913. (Purchase.)

Chemistry of Dye-stuffs. By Georg von Georgievics. London, 1903. (Purchase.)

Coal Tar Distillation and Working up of Tar Products. By Arthur R. Warnes. New York, 1914. (Purchase.)

Drying by Means of Air and Steam. Ed. 2. By E. Hausbrand, translated from the German by A. C. Wright. London, 1912. (Purchase.)

Handbook to the Technical and Art Schools and Colleges of the United Kingdom. London, 1909. (Purchase.)

Industrial Arts Index. Second Annual Cumulation, 1914. White Plains, N. Y., 1914. (Purchase.)

Ink Manufacture. Ed. 2. By Sigmund Lehner. London, 1914. (Purchase.)

Manufacture of Alum and the Sulphates and other Salts of Alumina and Iron. By Lucien Geschwind, translated from the French by Chas. Salter. London, 1901. (Purchase.)

Michigan Engineering Society (formerly Michigan Association of Surveyors & Civil Engineers) Proceedings of Annual Meetings. 1-3, 5, 7-8, 10-16, 19-22, 24-25, 27-34. v.p. 1880-82, 1884, 1886-87, 1889-1895, 1898-1901, 1993-04, 1906-14. (Gift of Michigan Engineering Society.

Mineral Waxes, their preparation and uses. By Rudolf Gregorius, translated from the German by Chas. Salter. London, 1908. (Purchase.)

New International Encyclopaedia. vols. 7-8. New York, 1914. (Purchase.)

Is Railroad Regulation Becoming Strangulation? By I. L. Lee. Address before Highland Park Church, Men's League. New Brunswick, N. J., Nov. 20, 1914. (Gift of Fairfax Harrison.)

Railways and Prosperity. Address by W. G. Harding, at the annual dinner of the Railway Business Association, Dec. 10, 1914. (Gift of Fairfax Harrison.)

Safety Rules. The Metropolitan West Side Elevated Railway, Northwestern Elevated Railroad, South Side Elevated Railroad, Chicago and Oak Park Elevated Railroad. n.p. n.d. (Gift of Northwestern Elevated Railroad Co.)

A Statesman's Opportunity. An address before the Railway Business Association, New York, Dec. 10, 1914. By Fairfax Harrison. (Gift of Fairfax Harrison.)

Water Terminal and Transfer Facilities. Letter from the Acting Secretary of War. (U. S. House of Representatives, 63d Congress, 1st session, document no. 226.) Washington, 1913. (Gift of Thos. G. Patten.)

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Total 52.

SECTION II

PROCEEDINGS

of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 17, 1915, under the auspices of the High-Tension Transmission Committee.

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(*Subject to final revision for the Transactions.*)

COMPARISON OF CALCULATED AND MEASURED CORONA LOSS CURVES

BY. F. W. PEEK, JR.

Abstract of Paper

Corona loss curves made on a number of experimental and practical lines by different investigators have been corrected and plotted. The loss has been calculated by the quadratic law for each case under the same conditions as to spacing, conductor diameter, altitude, etc. and plotted for comparison.

It is of interest to note that the measured values were made at various parts of the country. The time period covers a number of years and the altitude varies from sea level to 10,000 ft. An exact check of calculated and measured losses cannot be expected, as the exact conditions are not always known as to conductor surface, wave shape, etc. Such losses are also difficult to measure, especially on practical lines where the voltage range is quite small and there are a large number of corrections to make. The check is as close as the accuracy of the measurements permit. The variations from the calculated values are in most cases due to the fact that practical measurements have been made on the unstable part of the curve below the visual critical voltage value. The losses at this part of the curve are fully discussed.

CORONA loss curves made on a number of experimental and practical lines have been collected and plotted. The loss has then been calculated by the quadratic law for each case under the same conditions as to spacing, conductor diameter, altitude, etc. and plotted for comparison. In all cases the full lines in the illustrations represent the calculated curves, while the broken lines represent the measured curves.

It is of interest to note that the measured values were made at various parts of the country, by independent investigators, and that the time period is a number of years. The altitude varies from sea level to 10,000 ft. An exact check of calculated and measured losses can not be expected, as the exact conditions are not always known as to conductor surface, wave shape, etc. Such losses are also difficult to measure, especially on practical lines, where the voltage range is quite small and there are large corrections to make. In most cases, when such loss curves on practical lines have been given, measurements have not been carried above the *visual critical corona point.*

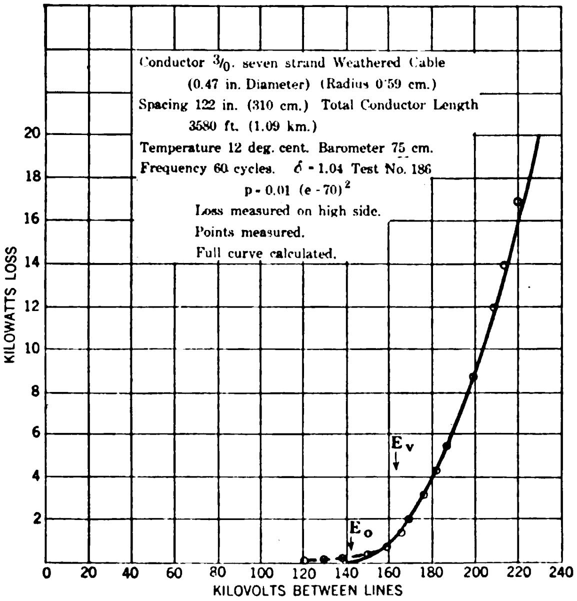
Manuscript of this paper was received December 24, 1914.

Before an examination of the curves is made, attention is called to the following summary of facts which are fully discussed in "Law of Corona I."*

The law of corona takes the general form

$$p = c\,(e - e_0)^2$$

which means that under conditions otherwise constant, the loss varies as the square of the applied voltage above a certain critical voltage, e_o or e_d. Figs. 1 and 2 show characteristic curves. The critical voltage, e_o, is called the *disruptive critical voltage.* Visual corona does not start at the *disruptive critical voltage,* but at some higher voltage e_v, the visual critical voltage. Both of these voltages have been calculated and marked on the curves. Theoretically, if the conductors were perfectly smooth, no loss should occur until the visual critical voltage, e_v, is reached, when the loss should suddenly take a definite value. For e_v, and higher voltages, the loss should follow the quadratic law.



Conductor 3/0. seven strand Weathered Cable
(0.47 in. Diameter) (Radius 0.59 cm.)
Spacing 122 in. (310 cm.) Total Conductor Length
3580 ft. (1.09 km.)
Temperature 12 deg. cent. Barometer 75 cm.
Frequency 60 cycles. $\delta = 1.04$ Test No. 186
$p = 0.01\,(e - 70)^2$
Loss measured on high side.
Points measured.
Full curve calculated.

FIG. 1—OUTDOOR SINGLE-PHASE EXPERIMENTAL LINE. (TESTS MADE BY F. W. PEEK, JR., SCHENECTADY, 1910)

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*Trans. A. I. E. E., 1911. See also *Law of Corona II* Trans. A. I. E. E., 1912. High Voltage Engineering, *Journal* of Franklin Institute, December, 1913.

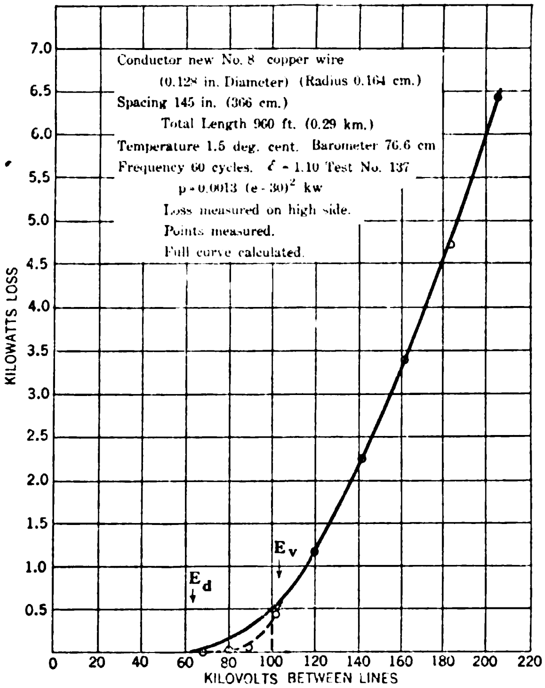

FIG. 2—OUTDOOR SINGLE-PHASE EXPERIMENTAL LINE. (TESTS MADE BY F. W. PEEK, JR., SCHENECTADY, 1910)

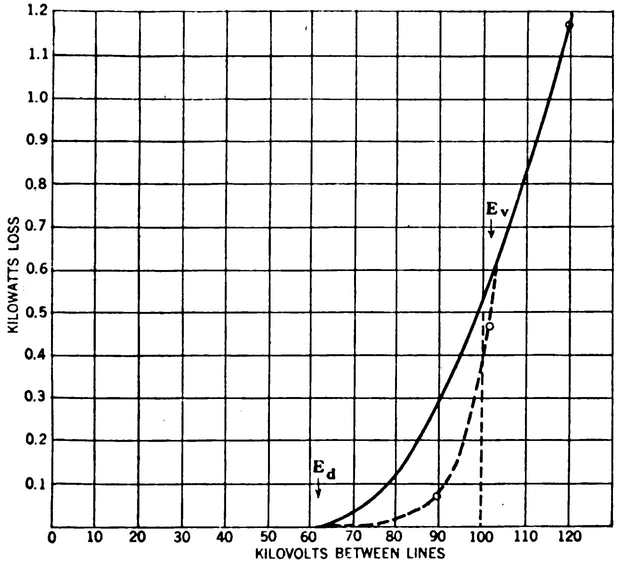

FIG. 3—LOWER PART OF FIG. 2 TO AN ENLARGED SCALE

In practise, due to dirt, points, etc., brushes occur on the conductors at voltages lower than e_v. Between e_v and e_o, due to these brushes, there is a loss. This loss practically follows the quadratic law for large weathered conductors, where e_v and e_o approach each other in value. See Fig. 1. For small conductors and especially new conductors with fairly clean surfaces, the loss between e_v and e_o falls below that of the quadratic law, as shown in Figs. 2 and 3. If the conductors were highly polished there would be very little loss until the voltage e_v is reached. At this voltage the loss would suddenly take a definite value very nearly equal to that calculated by the quadratic law with e_v as the applied voltage and e_o as the critical voltage in the equation.* In all cases the loss follows the quadratic law above e_v. The part of the loss curve between e_o and e_v

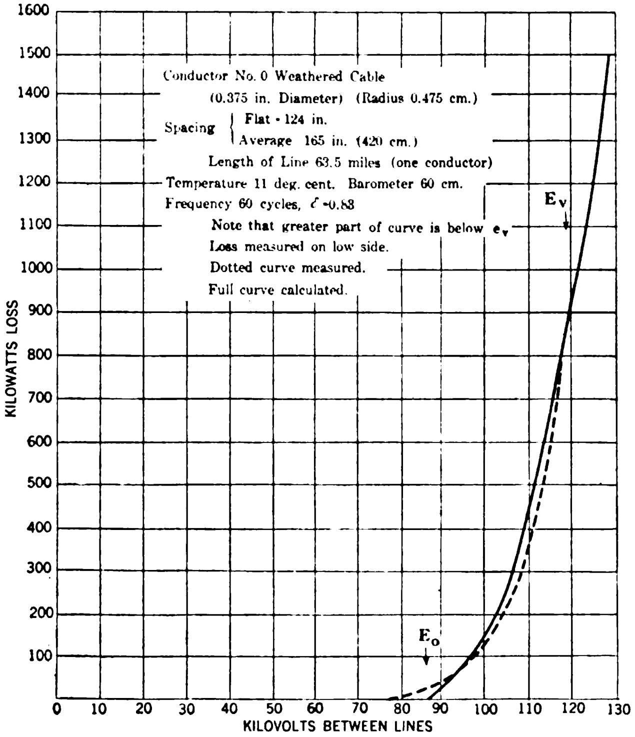

FIG. 4—SHOSHONE-LEADVILLE TRANSMISSION LINE, THREE-PHASE. (TESTS MADE BY FACCIOLI)

will thus vary from day to day depending upon the chance condition of the conductor surfaces. Over this unstable section of the curve the loss follows the probability law. It is of practical importance only to know the limits of the loss at this part of the curve; e_0 should generally be the limit of voltage on practical lines, as otherwise storm losses become excessive.

---

* e_o or e_d must always be used as the critical voltages in quadratic law.

Thus, from the considerations above, the quadratic law should be closely followed in all cases for voltages higher than e_v. For *the part of the curve between* e_v *and* e_0 the loss in unstable and dependent upon chance surface conditions, dirt spots, etc. as follows:

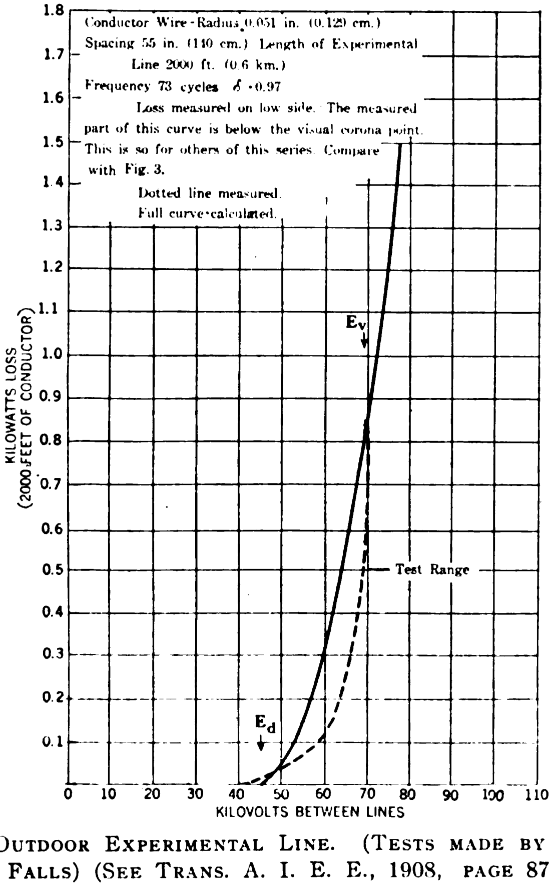

FIG. 5—OUTDOOR EXPERIMENTAL LINE. (TESTS MADE BY MERSHON, NIAGARA FALLS) (SEE TRANS. A. I. E. E., 1908, PAGE 876, FIG. 27)

1. For large weathered cables, such as are used in practical lines, the quadratic law is closely followed.

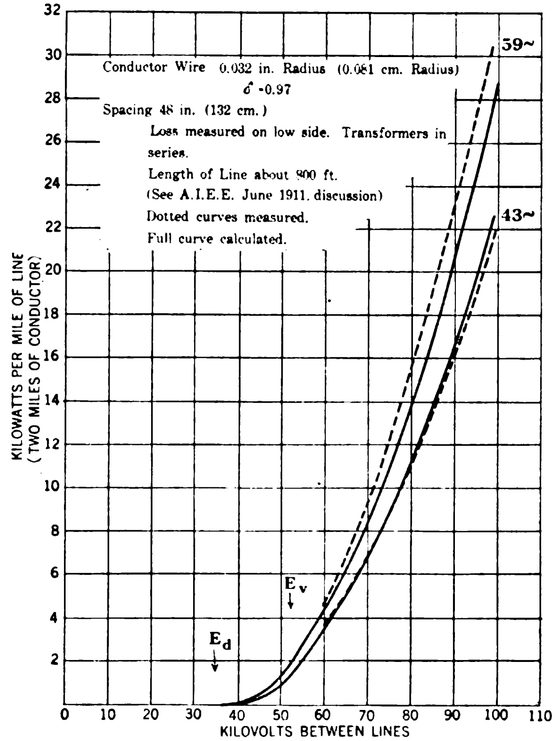

FIG. 6—OUTDOOR EXPERIMENTAL LINE. (MEASUREMENTS MADE BY A. B. HENDRICKS, PITTSFIELD, 1906)

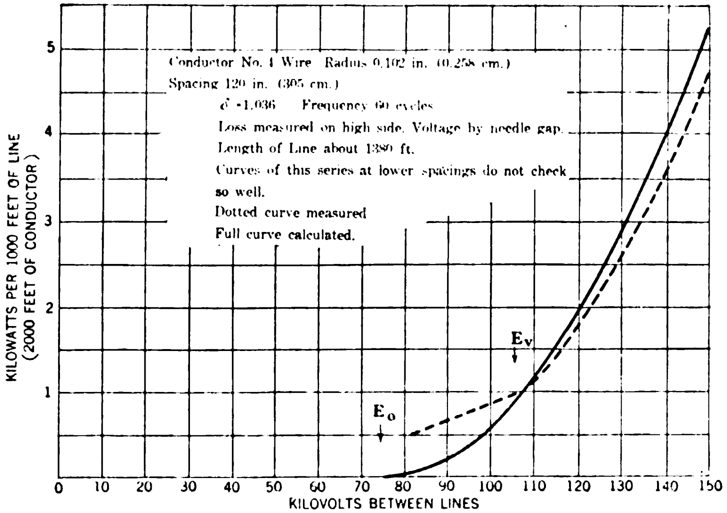

FIG. 7—OUTDOOR EXPERIMENTAL LINE. (TESTS MADE BY HARDING, PURDUE UNIVERSITY). (SEE TRANS. A. I. E. E. 1912, PAGE 1035)

2. For new conductors, and especially small ones, the loss at voltages lower than the visual critical voltage, e_v, falls below the quadratic law.

Figs. 1 and 4 are typical of condition (1), while Figs. 2 and 5 are typical of condition (2).

Figs. 1 to 7 show a remarkably good check between calculated losses and data available from measured losses. Another check, which is given in the N. E. L. A. Bulletin for June, 1912, [*] might be mentioned here. This paper states that the loss roughly measured on the Eastern Michigan line by station instruments was between 15 and 20 kw. per mile. This line is of No. 0 copper at an average spacing of 174 in. The voltage was 140 kv. at one end and 165 kv. at the other during the test. Under these conditions, the average calculated loss per mile is 15 kw.

The many hundred tests, made on our experimental outdoor and indoor lines, from which the quadratic law was derived, check as in Figs. 1 and 2.

The following formulas were used in making these calculations:

Visual Corona.

$$e_v = m_v g_v \, r \log^{e} \frac{S}{r} \text{ kv. to neutral}[\dagger]$$

$$g_v = 21.2\,\delta \left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \text{ kv. per cm. (effective sine wave)}$$

Corona Loss.

[‡]For practical transmission lines and frequency near 60 cycles:

$$p = a\,f\,(e - e_0)^2 \times 10^{-5}$$

$$e_0 = m_0\,\delta g_0 \, r \log_e \frac{S}{r} \text{ kv. to neutral}[\dagger]$$

[§]For small wires and calculation over a greater range of frequency, etc:

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[*] G. Faccioli, " Corona on High Tension Lines," N. E. L. A., Bulletin, June, 1911.

[†] Kilovolts between lines divided by 2 for single-phase and $\sqrt{3}$ for three phase.

[‡] *Law of Corona I and II*, Trans. A. I. E. E., 1911 and 1912.

[§] High Voltage Engineering, F. W. Peek, Jr., Franklin Institute, December, 1913.

$$p = 241\,(f + 25)\sqrt{\frac{r + \frac{6}{S} + 0.04}{S}}\,(e - e_d)^2 \times 10^{-5}$$

$$e_d = m_0\, g_d\, r \log_\epsilon \frac{S}{r}$$

$$g_d = g_0\delta\left(1 + \frac{0.3}{\sqrt{\delta r}}\,\frac{1}{1 + 230\, r^2}\right)$$

The probability law

$$p_1 = q\epsilon^{-h(e_0 - e)^2}$$

where

p = loss in kilowatts per kilometer of a single-line conductor.

e = effective value of the voltage between line conductors and neutral in kilovolts.

f = frequency.

$a = \frac{344}{\delta}\sqrt{\frac{r}{S}}$

r = radius of conductors in cm.

S = spacing between conductors in cm.

δ = air density factor = $\frac{3.92\,b}{273 + t}$ b = barometer in cm.
t = temperature deg. cent.

g_0 = 21.2 kv. per cm. effective sine wave.

m_0 is a constant dependent upon the surface condition.

m_0 = 1 for polished wires.

m_0 = 0.98 to 0.93 for roughened or weathered wires.

m_0 = 0.87 to 0.83 for cables.

m_v = m_0 for wires.

$$m_v = \left.\begin{array}{l}0.82 \text{ part corona}\\ 0.72 \text{ complete corona}\end{array}\right\}\text{cables.}$$

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 18, 1915, under the auspices of the Electrophysics Committee.

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(*Subject to final revision for the Transactions.*)

DISTORTION OF ALTERNATING CURRENT WAVE CAUSED BY CYCLIC VARIATION IN RESISTANCE

BY FREDERICK BEDELL AND E. C. MAYER

ABSTRACT OF PAPER

An alternating current flowing through an unvarying non-inductive resistance has a wave-form that is undistorted and is identical with the wave-form of electromotive force. If the resistance varies during each cycle, on account of changing current and temperature or other causes, the current wave-form will be distorted and will contain a third harmonic that will flatten the current wave when the temperature coefficient is positive and will peak the current wave when the temperature coefficient is negative.

If there is no temperature lag in the resistance (that is, if the maxima and minima of temperature and resistance coincide with the maxima and minima of current), the maximum of the third harmonic in the current wave will coincide with the maximum of the fundamental, so as to flatten or peak the wave as stated. A temperature lag in the resistance, however, causes the third harmonic of the current to be retarded in phase, and likewise causes a slight shifting of the fundamental of current with respect to the electromotive force.

Due to this distortion of current wave-form, power factor becomes less than unity and a vector diagram in more than two dimensions is required to show the true relations between current, electromotive force and power factor.

These conclusions, reached theoretically, conform with the experimental facts so far as known. In practical cases cyclic change of resistance is so small that the distortion due to it is insignificant.

IN A non-inductive circuit, the resistance of which remains constant during the cycle, an alternating current has exactly the same wave-form as the electromotive force impressed upon the circuit, for the current at each instant is directly proportional to the electromotive force at that instant. This is not true, however, if the resistance of the circuit changes during the cycle, as it does when the circuit consists of an incandescent lamp or lamps. In this case, since $i = e \div r$, the value of the current at any instant does not depend upon the electromotive force alone but depends also upon the value of the resistance at that instant; the wave-form of current is, accordingly, no longer the same as the wave-form of electromotive force. A simple sine electromotive force does not, in this case, produce a simple sine wave of current but a complex wave made up of a

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fundamental and one or more higher harmonics. It is the purpose of this paper to make a theoretical study of these harmonics and to see to what changes in resistance a particular harmonic corresponds. The conclusions which follow agree with experimental facts, so far as they are known.

If the resistance passes through the same series of values during the negative half-wave of current as during the positive half-wave, the negative half-wave will be a repetition of the positive, with sign changed, and, on account of this symmetry, the current wave can contain no even harmonics. (Even harmonics would be introduced, however, by a discriminating resistance having different values for positive and for negative currents; but it is not the purpose of this paper to consider resistances of this kind.)

It will be shown later, in connection with Fig. 10, that no harmonic other than the third can produce an effect consistent with physical facts, if it alone is present or predominant. Particular attention will, therefore, be given to the third harmonic and the cyclic change in resistance corresponding to it.*

Let it be assumed that the electromotive force is a sine wave, as curve e in Figs. 1 to 6, and that the current, i, consists of a fundamental, i_1, and a third harmonic, i_3, with maximum value equal to ten per cent of the maximum value of the fundamental. The phase of the fundamental and of the third harmonic with respect to the electromotive force will be represented by θ_1 and θ_3, respectively.

Irrespective of the value of r, the current must be zero when the electromotive force is zero, for $i = e \div r$, and this fact has been made use of in constructing the curves.

In constructing Figs. 1 to 6, the procedure has been as follows: First the electromotive curve e, a sine curve, is drawn. The third harmonic, i_3, is then drawn in some assumed phase position, as shown by the figure and indicated by the value of θ_3. Next, the fundamental of current, i_1, is so located that, when the electromotive force is zero, i_1 and i_3 will have equal and opposite values; the total current i is thus made zero when the electromotive force is zero, a necessary condition as already pointed out. Finally, the curve i for total current is drawn as the sum of i_1

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*A similar study has been made of the distortion of wave-form in a circuit embracing iron; see *Effect of Iron in Distorting Alternating Current Wave Form*, by F. Bedell and E. B. Tuttle, Trans. A. I. E. E., p. 671, Vol. XXV., 1906.

and i_3; and the curve r is drawn showing the instantaneous values of resistance, $r = e \div i$.

On the right, in each figure, the broken curve r shows the value of resistance for each value of current; the solid curve shows the relation between e and i. Except in Figs. 1 and 4, it will be seen that r and e have different values for increasing and decreasing values of i.

Discussion of Curves. Fig. 1 shows that a third harmonic of current in phase with e, ($\theta_3 = 0$), flattens the current curve and corresponds to a resistance that increases with current, that is, the temperature coefficient is positive. Maximum resistance occurs, in Fig. 1, at the same time as maximum current; hence, in this case, there is no temperature lag. It is seen that the resistance has the same value for increasing and for decreasing current.

Since the resistance curve has maxima for negative and for positive current, the resistance curve has twice the frequency of the current curve.

Fig. 2 shows the same case as Fig. 1 except that the third harmonic of current is caused to lag a little, with respect to the electromotive force. As a result, the fundamental, i_1, is seen to be advanced in phase so that the sum of the fundamental and third harmonic of current is zero when the electromotive force is zero. The maximum resistance is now reached later, (approximately 30° later) than the maximum current, indicating a temperature lag. Resistance increases with current, indicating a positive temperature coefficient, but the maximum resistance is now reached later than the maximum current, and the resistance has different values for increasing and decreasing current, due to this temperature lag.

The curves on the right, accordingly, show resistance hysteresis loops.

Fig. 3 is the same as Fig. 2 with θ_3 increased to 30°. θ_1 now has its greatest possible value, for further increase of θ_3 decreases θ_1, as shown in Fig. 7.

Curves, not shown, have been drawn similar to Figs. 2 and 3 for all ranges of value of θ_3; the figures reproduced here are typical. They agree remarkably well with the experimental curves of Sahulka* and Bedell† made with incandescent lamps. These

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*" Wave Forms of Current and *Cp* of Alternating Current Lamps," by J. Sahulka, *Elec. World Digest*, p. 803, Vol. 49, 1907; original article in *Elek. und Masch.*, Feb. 17 and Mar. 17, 1907.

†" Measurement of Instantaneous Lamp Resistance," by F. Bedell, *Elec. World*, p. 370, Vol. 57, 1911.

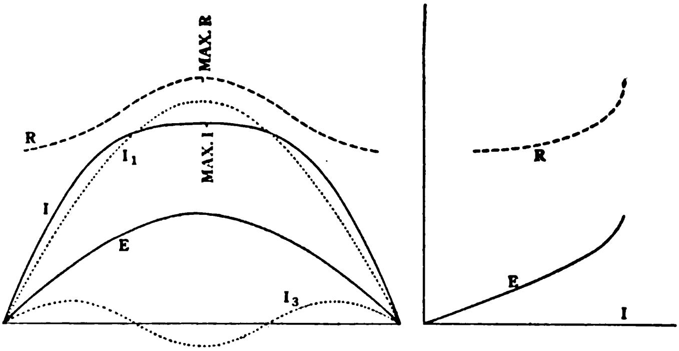

Fig. 1. $\theta_3 = 0$. θ_1 is then 0; I_1 and I_3 are in phase with E. Maximum R Coincides with Maximum I and there is no Temperature Lag. Temperature Coefficient is Positive

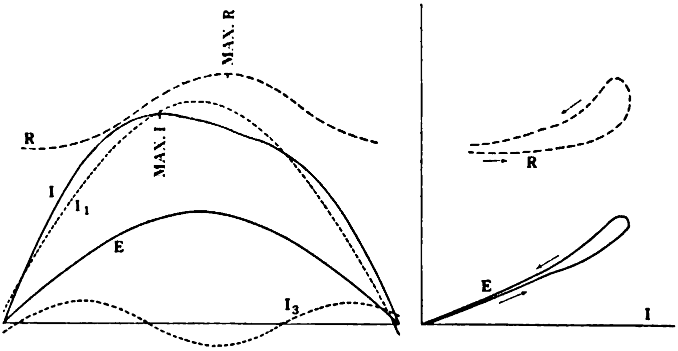

Fig. 2. $\theta_3 = -6°$ (Approx.), I_3 being Retarded in Phase. I_1 is then Advanced so that $\theta_1 = +2°$. Maximum R Lags 30° behind Maximum I, Due to Temperature Lag. Temperature Coefficient is Positive

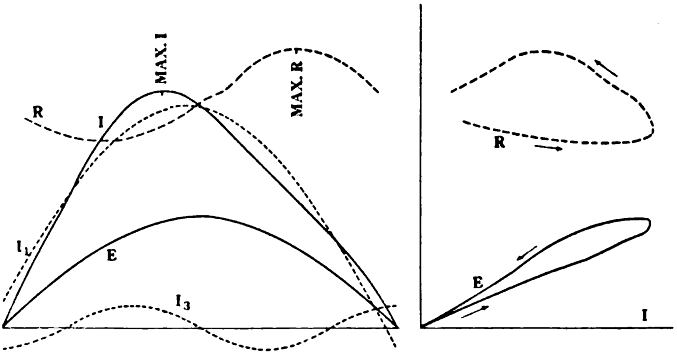

Fig. 3. $\theta_3 = -30°$, I_3 Being Further Retarded; I_1 is then Advanced so that $\theta_1 + 5.75°$. Maximum R Lags 60° Behind Maximum I Due to Temperature Lag. Temperature Coefficient is Positive

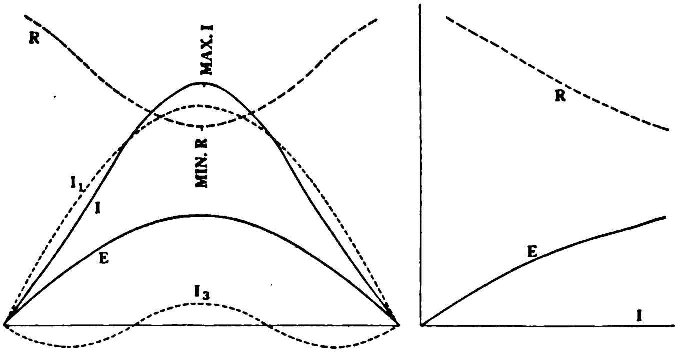

Fig. 4. $\theta_3 = -60°$. θ_1 is then 0. I_3 is just Opposite to I_3 in Fig. 1. Minimum *R* Coincides with Maximum *I* and there is no Temperature Lag. Temperature Coefficient is Negative

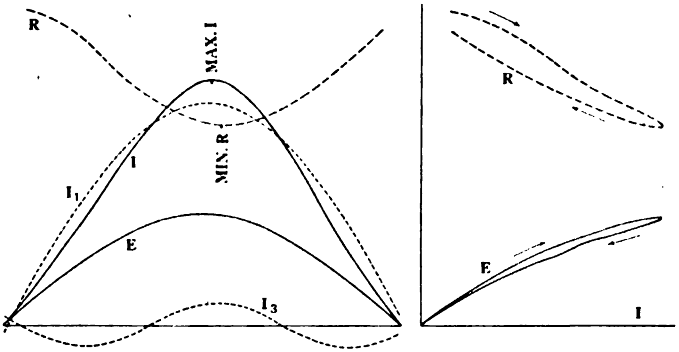

Fig. 5. $\theta_3 = -66°$ (Approx.), I_3 being Retarded about 6°. I_1 is then Retarded so that $\theta_1 = -2°$. Minimum *R* Lags 5° Behind Maximum *I*, due to Temperature Lag. Temperature Coefficient is Negative

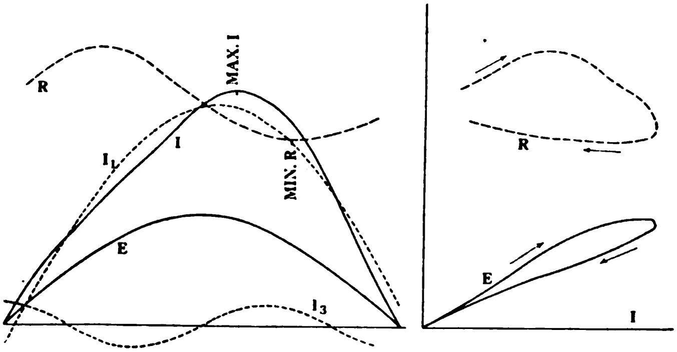

Fig. 6. $\theta_3 = -90°$, I_3 being Further Retarded. *I* is then Retarded so that $\theta_1 = -5.75°$. Minimum *R* Lags 30° Behind Maximum *I*. Temperature Coefficient is Negative

theoretical curves, however, are much exaggerated in order to illustrate clearly the character of the results and show 30 to 40 per cent. change in resistance during a cycle, whereas the experiments‡ referred to showed a change of only one or two per cent.

It will be seen, in Figs. 2 and 3, that the third harmonic of current is lagging, θ_3 being negative. The corresponding cases with θ_3 positive would be shown by Figs. 2 and 3 reversed as in a mirror; the maximum resistance would then be reached *before* instead of *after* the maximum current, indicating a temperature advance instead of a temperature lag. As this would be inconsistent with physical fact, it may be concluded that the third harmonic must lag as shown in Figs. 2 and 3.

Figs. 4, 5 and 6 show cases corresponding to those shown in Figs. 1, 2 and 3, the third harmonic, however, being reversed. The current wave is now seen to be peaked instead of flattened. The resistance in these cases is found to *decrease* with current, corresponding to a temperature coefficient that is *negative* instead of positive.

In Fig. 4, the resistance has the same values for increasing and decreasing current, there being no temperature lag and no hysteresis in the resistance changes; the *minimum* resistance coincides with maximum current.

In Figs. 5 and 6, minimum resistance occurs *after* maximum current; these figures show a temperature lag and resistance hysteresis. The fundamental of current in Figs. 5 and 6 is lagging instead of in advance of the electromotive force, as in Figs. 2 and 3, so that its value at the moment of zero electromotive force will be equal and opposite to the value of the third harmonic.

In passing from Fig. 1 to Fig. 3, the flattening becomes less pronounced as the current curve becomes less symmetrical. Similarly, in passing from Fig. 4 to Fig. 6, the distortion of the current curve does not make so definite a peak.

Fig. 7 shows the relation between θ_1 and θ_3, determined by the condition that the instantaneous values of the fundamental and third harmonic must be equal and opposite at the moment when the electromotive force is zero. Fig. 7 is drawn for the case in which the third harmonic is ten per cent. of the fundamental. Even in this exaggerated case, it is seen that the lag or lead of the fundamental cannot exceed 5.75°, and this possible phase difference would be less if the third harmonic were less. In practical cases, therefore, the phase, shift of the fundamental current due to resistance change will always be small.

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‡Experiments might be made with resistance having a much higher temperature coefficient than incandescent lamps. A boron resistance has been described by Dr. E. Weintraub the conductivity of which doubles for 17°C change in temperature; see *Elec. World*, Vol. 63, p. 1098, May 16, 1914.

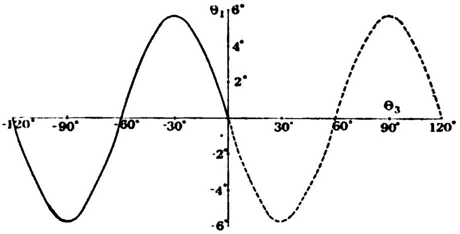

FIG. 7—VALUES OF θ_1 FOR DIFFERENT VALUES OF θ_3

Figs. 8 and 9 show the amount of lag in maximum or minimum resistance, after maximum current is reached, for different values of θ_3. Points *a*, *b*, *c*, *d*, *e*, *f* were determined from Figs. 1 to 6, respectively, other points being determined from similar curves not here reproduced. The amount of lag can be only approximately determined from the curves in each case. In view of this fact the results in Figs. 8 and 9 seem quite consistent. In Figs. 7, 8 and 9, negative values of θ_3 correspond to temperature lag; positive values would correspond to a temperature advance, as already pointed out.

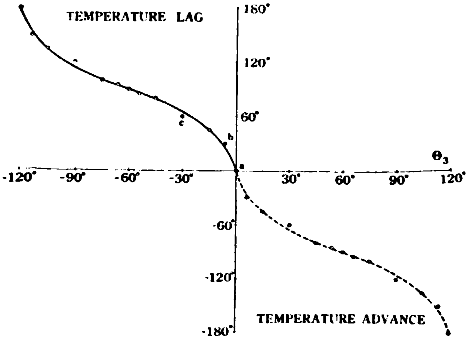

FIG. 8—LAG OF MAXIMUM *R* BEHIND MAXIMUM *I* DUE TO TEMPERATURE LAG. POINTS *a*, *b*, *c* CORRESPOND TO FIGS. 1, 2 AND 3, TEMPERATURE COEFFICIENT POSITIVE.

In the foregoing discussion, resistance has been considered as a function of current, the relation between resistance variation and wave form of current being the object of the investigation. If, in Figs. 1 to 6, curves were drawn for instantaneous power, by taking the product $e \times i$, these curves, as is well known, would be curves of twice the frequency of e or i. In Figs. 1 and 4 the double frequency curve for r would have its maxima and minima (or minima and maxima) coincident with the maxima and minima of the power curve. In the other figures the double frequency resistance curve would lag behind the double frequency power curve, and this lag behind the power curve would not be identical in amount with the lag behind the current. As power depends upon e as well as i, maximum power is not coincident with maximum i but, in case of smooth curves as here discussed, is between maximum e and maximum i.

Fig. 10 shows the change of resistance with current which would be necessary to produce a fifth harmonic. Inflections, as shown in Fig. 10 for a fifth harmonic, would occur in resistance curves drawn for any harmonic above the third. Such curves do not agree with the physical facts, as do the curves drawn for a third harmonic, Figs. 1 to 6. We, accordingly, conclude that the third harmonic must be predominant and that any higher harmonics must be relatively small.

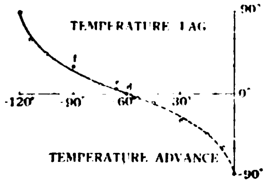

FIG. 9—LAG OF MINIMUM R BEHIND MAXIMUM I DUE TO TEMPERATURE LAG. POINTS d, e, f CORRESPOND TO FIGS. 4, 5 AND 6, TEMPERATURE COEFFICIENT NEGATIVE.

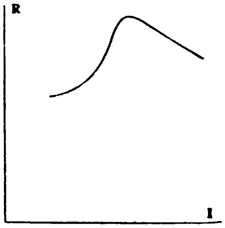

FIG. 10—CHANGE OF RESISTANCE WITH CURRENT NECESSARY TO PRODUCE A TEN PER CENT FIFTH HARMONIC; $\theta_3 = 0$. TEMPERATURE COEFFICIENT POSITIVE

Power Factor. With a sine electromotive force, there is power in the fundamental current only, there being no power in any harmonic in the current that does not have a corresponding harmonic in the electromotive force. The true power is, accordingly, $E\,I_1 \cos \theta_1$. The apparent power is EI, where I is the effective value of the total current; $I^2 = I_1^2 + I_3^2 + I_5^2 + I_7^2 \ldots\ldots$

Power factor, the ratio of true to apparent power, is, accordingly, equal to cos $\theta_1 \times I_1 \div I$, being the product of the fundamental power factor and a distortion factor, $I_1 \div I$, always less than unity. Power factor is independent of θ_3.

A third harmonic of ten per cent. gives a distortion factor of 0.995 and, for the cases shown in Figs. 1 to 6, the power factor is cos $\theta_1 \times 0.995$. When $\theta_1 = 0$, Figs. 1 and 4, the power factor has its maximum value 0.995. When $\theta_1 = 5.75°$, Figs. 3 and 6, the power factor has its minimum value 0.990.

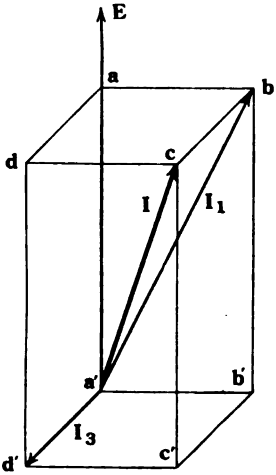

FIG. 11—VECTOR DIAGRAM IN THREE DIMENSIONS

Vector Representation. The vector representation of a sine electromotive force, E, and a distorted current, I, is shown in Fig. 11. The fundamental plane (the plane of the paper) is determined by E and the fundamental current, $I_1 = a'b$, the phase difference between them being $\theta_1 = aa'b$.

The third harmonic current, I_3, is represented by $a'd'$ at right angles to the fundamental plane,* irrespective of the value of θ_3. (This line represents any harmonic, not necessarily the third. If several harmonics are present, it represents their combined value, $I_h = (I_3^2 + I_5^2 + I_7^2 + \ldots\ldots)^{\frac{1}{2}}$. It will, however, be referred to here as the third harmonic.)

The total current I is represented by $a'c$, the vector sum of I_1 and I_3 and fulfills the condition,

$$I^2 = I_1^2 + I_3^2.$$

The fundamental power factor is $\cos \theta_1 = \cos aa'b$.

The distortion factor (as used above) is $I_1 \div I = \cos ca'b$.

The total power factor, or $\cos \theta$, is the product of these two, that is

$$\cos \theta = \cos \theta_1 \times I_1 \div I;$$

or, $\cos aa'c = \cos aa'b \times \cos ca'b$.

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*This representation of harmonics by vectors out of the fundamental plane was described by one of the writers at a meeting of the Physical Society in June, 1906; see "Note on the Graphical Representation of Non-Sinusoidal Alternating Currents," by F. Bedell, *Phys. Rev.*, Vol. XXIII., p. 249; also Bedell and Tuttle, *loc. cit.*

It is seen that, unless I_3 is zero and the current is a sine wave, there is no value of θ_1 that brings I in phase with E; that is, θ is never zero and cos θ is never unity.

Summary. Cyclic change in resistance distorts the current wave and this distortion is accounted for chiefly by the introduction of a third harmonic. This harmonic has such a phase position as to flatten the current wave slightly when the temperature coefficient is positive and to peak the wave when the temperature coefficient is negative. The third harmonic lags in phase, from a symmetrical position indicated by $\theta_3 = 0°$ or $60°$, by an amount dependent upon the amount of temperature lag; this causes a slight shifting in phase of the fundamental, advancing the fundamental in phase when the temperature coefficient is positive and retarding it in phase when the temperature coefficient is negative.

On account of the distortion of current, power factor is slightly less than unity. A vector diagram in three dimensions shows the relations between current, electromotive force and power factor.

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915, under the auspices of the Industrial Power Committee.

Coypright 1915. By A. I. E. E.
(*Subject to final revision for the Transactions.*)

THE CHARACTERISTICS OF ELECTRIC MOTORS INVOLVED IN THEIR APPLICATION

BY D. B. RUSHMORE

ABSTRACT OF PAPER

Industrial power work in the electrical field consists primarily in applying electric motors to the driving of various kinds of machinery. The machines to be driven possess characteristics of different kinds and are run on duty cycles which are often peculiar to the classes of industry involved. Generally the characteristics of the machine to be driven are fixed and the class of motor suitable for this work must be selected with regarded to these features.

Motors themselves are adapted to the work of driving machines largely through various forms of controllers. A study of the characteristics of various classes of electric motors in the light of their adaptability to the requirements of the work to be done and a review of certain limitations and mechanical considerations is the object of the paper.

EVOLUTION OF THE ELECTRIC MOTOR

NEARLY one hundred years have elapsed since A. M. Ampere announced his discovery of the dynamic action between conductors conveying electric currents, this being shortly followed by Michael Faraday's discovery of the principles of electromagnetic induction, which laid the foundation for all subsequent inventions leading to the production of electromagnetic or dynamo-electric machines. Actual industrial motor applications were tried out as early as 1858, the current being obtained from batteries, but it was not until 1873 that the reversible action of the dynamo was discovered by Messrs. Gramme and Fontaine at the Vienna Exposition.

The polyphase induction motor was invented independently by Tesla and Ferraris during the period of 1885-88, and the development of this type of motor has been astonishing. When only a few years ago it was built in sizes of comparatively moderate capacity, we now find units in capacities of 6500 horse power.

Manuscript of this paper was received January 8, 1915.

STATISTICS

The enormous increase which has taken place during past years in the application of electric motors for driving industrial machinery, is best illustrated by a reference to the U. S. Census Reports given in Tables I and II.

TABLE I

ELECTRIC MOTORS IN MANUFACTURING

	1899	1904	1909
Run by rented power	182,562 h. p.	441,589 h. p.	1,749,031 h. p.
Run by power generated by establishment	310,374	1,150,886	3,068,109
Total horse power	492,936	1,592,475	4,817,140

TABLE II

ELECTRIC MOTORS IN LEADING INDUSTRIES

	1899	1904	1909
Agricultural implements	7,643	20,713	38,905
Automobiles		4,229	41,829
Car and railroad repair shops	4,563	52,635	161,288
Cement		35,292	158,749
Cotton goods	17,594	67,139	235,902
Electrical machinery	24,256	61,753	164,540
Foundry and machine shops	54,907	199,625	623,914
Iron—Steel, blast furnaces	8,693	52,610	135,143
Iron—Steel, Steel works and rolling mills	64,658	254,258	716,609
Lumber and timber products	11,315	33,517	130,707
Paper and wood pulp	2,814	31,604	130,120
Printing and publishing	41,413	93,219	229,312

TABLE III

PRIMARY POWER

	1899	1904	1909
Owned			
Steam	8,139,579	10,825,348	14,202,137
Gas	134,742	289,423	754,083
Water	1,454,112	1,641,949	1,807,144
Other	49,985	98,085	44,742
Rented	319,475	632,902	1,872,670
Total horse power	10,097,893	13,487,707	18,680,776

It is thus seen that at the end of the 10-year period 1899-1909 the use of motors has increased to ten times what it was at the beginning of this period, while in certain industries the increase was even greater. This enormous rate is even more apparent by a reference to Table III which gives the increase in the primary power used, this being not quite doubled during this period.

ADVANTAGES OF ELECTRIC MOTOR DRIVE

In general the use of electric motors for driving industrial machinery offers the same advantages for all kinds of applications the distinctly important features being a decreased power consumption and an increased production for a given equipment.

Among the features which aid in bringing about this condition are:

Centralized power supply.

Simplicity of power transmission and distribution.

Machinery may be conveniently located with reference to production rather than to the power transmitting system.

Changes can easily be made.

Reduced friction losses and thus increased efficiency.

Cleanliness and better light due to the absence of the large number of belts.

Less danger of accidents.

Better reliability of operation.

Wide choice of motors as to size, mechanical design and operating characteristics.

Perfect control, including readiness of starting and stopping and making close speed adjustments.

Remote and automatic control.

The operations may be closely studied by means of recording devices and tests can readily be made.

Economy in time.

Ability to operate any portion of a factory at any time with a power consumption approximately proportional to the work done.

Etc., etc.

APPLICATIONS

The application of a motor to a certain machine involves not only a careful study of the conditions under which the machine is to operate, but also of the characteristics of the motor to be applied to it. The former includes a full knowledge of the duty cycle, the method of drive and the conditions of the location, while the latter covers the important features relating to the operation of the motor itself, including the advantages and limitations of each type.

CLASSIFICATION

Motors may be classified either according to type, speed, mechanical features, etc. The first cover:

- Direct Current.
  - Series.
  - Series-Shunt.
  - Shunt.
  - Compound.
  - Differential.
- Alternating Current (Single-phase and Polyphase).
  - Synchronous.
  - Synchronous-Induction.
  - Induction.
    - Phase-Wound.
    - Squirrel-Cage.
  - Commutator.
    - Series Characteristics.
    - Shunt Characteristics.
    - Compound Characteristics.

RATING

In order to correspond as closely as possible to the duty cycle, motors are given different ratings, and the three principal kinds of service which motors are required to meet are:

1st: Continuous duty where the load is practically constant over long periods of time.

2nd: Cycle duty, in which a definite cycle repeats itself with more or less regularity, the machine stopping between each cycle.

3rd: Varying load duty in which more or less definite cycles are repeated, but the motor runs continuously.

These last two ratings, for convenience, are combined into a short-time rating and the rating thus derived is simply a calibration of the motor for its particular service, and this refers particularly to heating. The other limitations, such as the commutation and mechanical strength of the heavier part of the cycle, have to be chosen from the duty which the motor is to perform.

LIMITATIONS

The principal limitations in the rating of motors are:

Mechanical Strength.
Heating.
Commutation.
Regulation.
Efficiency.

The length of life of the brushes and commutator depends, of course, on the quality of commutation, and for continuous-duty service this should be the best possible. On short-time rated motors some sparking may be permitted without seriously shortening the life of the machine or require frequent renewals. Such cases are where the peaks come few and far between, so that the commutator and brushes may have time to convalesce between such sparking periods, due to polishing.

With a geared machine which automatically starts, stops or reverses after a predetermined number of revolutions, such as on planers, etc., the sparking will, however, always occur on the same segments of the commutator, and under this condition sparkless commutation must be maintained on all peaks, or serious deterioration will take place.

Regulation is a more or less important factor in some applications, and for such drives as paper machines, cutting tools, etc., it may be the limiting feature.

The efficiency of continuous-running apparatus is also usually of great importance. While on many types of cycle-duty operation it is of secondary importance, oftentimes it need not be considered at all. In cases where a motor runs practically all of the time on armature control, or where starting torque and running for a few seconds is the only requirement of the motor, such as a valve motor, the efficiency can be neglected. As a matter of fact, were the motor solely designed for efficiency it would be deterimental, as it would run up the first cost, weight and dimensions with no adequate return.

In general, the power factor of motors need only be considered from the dollars and cents standpoint of supplying current to the motor. While, in general, motors of high power factor are desirable, it is advisable in many cases, and often necessary, to sacrifice power factor for other characteristics for a successful drive.

SPEED CLASSIFICATION

Motors are often also classified with reference to their speed characteristics, as follows:

Constant Speed: covering cases where the speed is constant or varies only slightly.

Adjustable Speed: covering cases where the speed may be varied over a considerable range, but when once fixed remains at this value independent of the load changes.

Varying Speed; covering cases where the speed changes with the load, usually decreasing as the load increases.

Multi-speed; covering cases where several distinct speeds may be obtained (two-speed; three-speed) by changing the connections of the windings or other means.

CHARACTERISTIC CURVES

The characteristic curves of various motors must be studied with a view of their application of motors of the proper characteristics chosen to meet various applications. The torque, starting, running, maximum, may be required to be of very high values in all three, or any one, or any combination. Certain classes of machinery, for example, must have very high starting torque but the running torque may be low, or vice versa.

The characteristic curves usually cover:

Torque (starting, running, maximum).
Current (starting, running, maximum).
Efficiency.
Power Factor.
Speed Regulation.
Phase Characteristics (for synchronous motors).

MECHANICAL CONSIDERATIONS

According to their mechanical features motors may be classified as follows:

Open.
Mechanically protected.
Semi-enclosed.
Totally-enclosed.
Enclosed externally ventilated.
Enclosed self-ventilated.
Moisture proof.
Splash and water-proof.
Acid-proof.
Submergible.

It is important to know the conditions of location of the motor in order to determine the proper kind of insulation to use. Standard motors are provided with insulation suitable even when motors are operated under conditions of slight moisture. In addition, there are a number of special insulations which are to be used under abnormal conditions, such as:

When windings are exposed to moisture in excess of that for which standard insulation is designed.

For extreme tropical conditions and for use in very hot rooms filled with steam.

When windings are exposed to weak acid or alkaline vapors, excessive alkaline dust, etc. No insulation can, however, as a rule withstand strong acid or alkaline fumes.

When windings are run under conditions which will cause heating somewhat above normal.

When the windings are subject to very high temperatures.

Motors may be of the horizontal or vertical type and connected to the machinery either directly or through belt, chain, rope, gear or friction drives.

The bearings may be of the ordinary journal type, either babitted or lined with metaline as in cases where the lubrication is liable to be neglected. Of late years the use of roller and ball bearings has also increased rapidly.

Operating Features

From the operating point of view there is a large number of features which must be considered in connection with motor applications. Some of these are as follows:

Use of flywheels.

Stability of operation (motors dropping out of step on short-circuits in system).

Effect of voltage variation.

Effect of frequency variation.

Effect of wave form variation.

Effect of unbalancing of phase voltages.

Single-phase operation on three-phase circuits.

Limitations of throwing motors directly on line.

Effect on generating stations, lines and system in general when connecting motors in service.

Reversible service requires motors with small flywheel effect.

Phase advancement for improvement of power factor.

Etc., etc.

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 18, 1915. Under the auspices of Committee on Marine Work.

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SEARCHLIGHTS

BY C. S. McDOWELL

ABSTRACT OF PAPER

Searchlights have remained practically the same for the past 25 years, although there is great necessity of an improved searchlight on account of the increased range of torpedoes and increased speed of torpedo boats.

The constituent parts of a searchlight are given in the paper and some of the essential and desirable features of the various parts are shown. Methods of testing searchlight mirrors are given, with illustrative figures.

The results of tests conducted on Navy standard 36-in. and 60-in. searchlights and Beck 44-in. searchlight show the latter type to be much more efficient in illuminating distant objects. Relative results are shown in the figures.

SEARCHLIGHTS were first used during the Civil War in a very crude state; these first searchlights were fitted with metal mirrors. Later, Fresnel lenses were used to concentrate the beam. In 1876, the Mangin type of mirror was first brought out and in 1886, Schuckert, in Nuremburg, succeeded in producing a glass parabolic mirror ground to mathematical accuracy. Practically no changes have been made since that time to increase the efficiency of the searchlight; some mechanical improvements have been made, and methods of manufacture of carbons perfected, but practically the ordinary searchlight of to-day is the same as that of 25 years ago.

In view of the increasing speed of torpedo boat destroyers and the increased range of torpedoes, it is very important that the searchlight, one of the principal means of defence against night attack, should be improved if possible. There has lately been developed by Mr. Heinrich Beck of Germany, a new type of searchlight much more efficient than those now in use, which is described a little later in this paper.

In considering the question of searchlights and their relative efficiencies, it becomes natural to consider them as made up of the following constituent parts:

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1. Searchlight drum, pedestal, system of control in azimuth and in elevation, shutters and other purely mechanical details.
2. Rheostats.
3. Searchlight mirror.
4. Lamp mechanism.
5. Searchlight arc.

One type of searchlight may show increased efficiency over another because some of these parts have been worked out to give the very best results, but a searchlight to give the very best results must have all these details worked out separately and then joined together in the proper relation to give the maximum efficiencies.

Searchlight drum and other mechanical details are questions of design which affect the efficiency of the light very little. They should be worked out carefully, however, so that the searchlight is properly balanced, may be easily trained in azimuth and elevation from a distant control station or at the light itself. The drum should be so made that air currents cannot be set up inside, thereby causing flickering of the arc; ventilation should be sufficient so that light may be kept on at full intensity with shutter closed or other means adopted for keeping the light burning at lower intensities with shutter closed and bringing it to full intensity instantly upon opening of shutter. It is also considered advantageous to have a permanent ammeter and voltmeter mounted on the searchlight drum, or a connection on it so that portable instruments can be connected. A ground-glass finder which shows the position of the arc, the arc length, and the variations of the positive crater from the focus of the mirror is considered an essential in a properly designed searchlight. The mirror should be so secured that it may be readily removed and the mirror and front door strips should be mounted in such a manner as to eliminate shock and breakage.

The rheostat used in connection with searchlights consists of two parts: a fixed and a variable resistance. A certain amount of fixed resistance is necessary to overcome the natural unstability of a carbon arc and its value must be at least sufficient to give a voltage drop in the resistance equal to one-half the arc stream voltage. The variable resistance is necessary in order to obtain the proper arc voltages for various carbons and various lengths of line. The resistance elements must

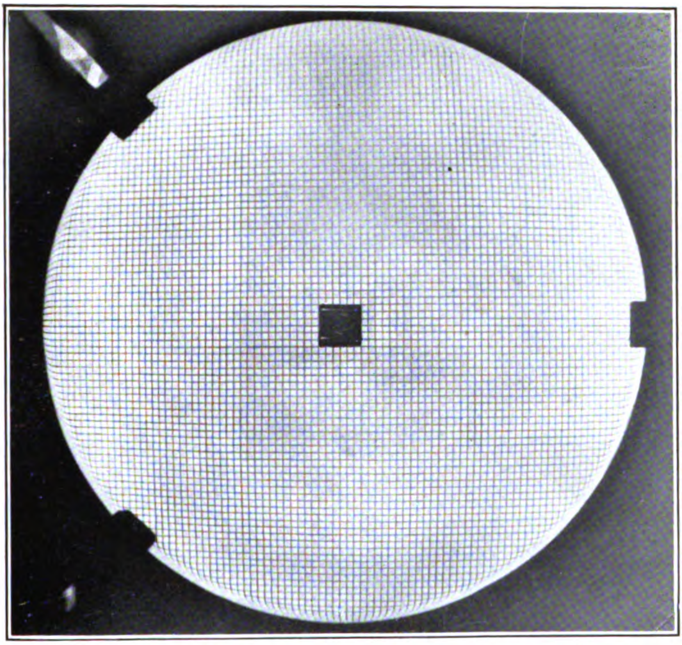


FIG. 1 [MCDOWELL]

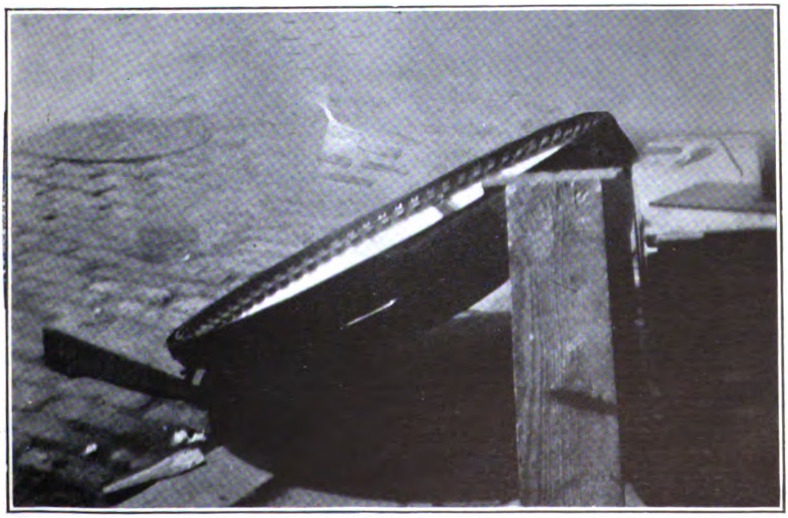
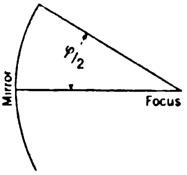


FIG. 2 [MCDOWELL]

be of sufficient area to carry the maximum currents used without undue heating of any parts and of such material that the resistance does not change excessively with temperature changes. The steps should be not greater than one volt each.

The efficiency of a searchlight mirror depends upon its trueness to parabolic form, its trueness of surface grinding, the color and structure of the glass, and the thickness of the glass. The losses in searchlight mirrors are due to stray rays outside of the conical beam and to absorption in the mirror. The intensity of illumination on a distant object, provided equal amounts of light fall on the mirror, is dependent on the efficiency of the mirror and the angle of dispersion (that is, at a distance, the area of the illuminated plane normal to beam).

The relation between the focal length and diameter of the mirror should be such that the effective angle φ should include the majority of light given off by the arc. By increasing the focal length, the diameter of mirror remaining constant, the ratio of the light falling on the mirror to the total given out by the arc is decreased but also the angle of dispersion is decreased, therefore, the correct focal length is that which, changed in either direction, decreases the foot-candle illumination on a distant object. If we increase the diameter of the mirror at the same time as the focal length is increased, the angle φ can be maintained constant and at the same time the dispersion decreased, thus giving greater intensity of illumination on a distant object. On board ship, however, the size of the searchlight and thus the diameter of the mirror is limited. A greater focal length is also of advantage in that it takes the arc farther from the mirror and thus decreases the chances of breakage of the mirror due to the heat of the arc.



In determining the efficiencies of searchlight mirrors, various tests are carried out:

(*a*) *The Line or Screen Test.* If we imagine a section taken through the center of the mirror, a curve is obtained whose curvature should vary in a regular manner from the center towards the edge, but the curve will take a wavy form instead if the surface has not been accurately ground.

The mirror is erected opposite a screen on which are painted two systems of parallel straight lines at right angles to one another. The image of these lines is photographed by a camera placed back of the hole in the center of the screen. If both surfaces of the mirror are properly ground the lines in the photograph should be regular but not necessarily straight nor parallel. This test does not show if the mirror is parabolic or not.

An illustration of a mirror showing this test is given in Fig. 1.

(*b*) *The Sun or Zone Test.* A perfect mirror should reflect rays from a point of light situated at its focus, in parallel straight lines. It must, therefore, also have the property of bringing a parallel beam of light, as from the sun, to a focus in a single point. This as made, consists in placing the mirrors in a plane perpendicular to the sun's rays and photographing the reflected focal point, brought out in contrast by blowing smoke on it.

An illustration of this test is shown in Fig. 2.

(*c*) *Beam Photometric Tests.* It is considered that the most reliable test of mirrors is to actually mount them in a searchlight, place a constant source of light in the focus, and at a standard distance measure the actual foot-candles of illumination throughout the entire beam. The focal point of a mirror to be tested is first accurately obtained (our method being to place two mirrors exactly parallel with each other about 30 ft. apart and place a concentrated filament lamp approximately at the focal point of the second and measure accurately the focal length of the first); the mirror under test is then mounted in a searchlight frame held in a fixed position, a concentrated filament lamp placed accurately in the focus (a 50-watt lamp is used) and at a standard distance measure the foot-candles by a portable photometer. These foot-candle readings are usually obtained every four inches across the beam on two lines perpendicular to each other and passing through the center. For the larger size mirrors 200 feet has been taken as the standard distance. Curves obtained in this test are shown in Fig. 3.

By calculating the amount of light flux falling on the mirror and that received on the distant object the losses in the mirror may be found and the coefficient of reflection obtained.

In a number of cases, mirrors which showed nearly perfect grinding and sharp focal point, as determined by the first two tests, were found on this third test to reflect less light than other mirrors which had shown much poorer results on the screen and zone tests.

The lamp mechanism of a searchlight should be such as to keep the crater of the positive carbon at the focus of the mirror, should keep the arc length that which is desired, should carry the current of the carbons, should contain mechanism for rotating at least the positive carbons, should be sufficiently rigid to keep the carbons in proper alignment, and should require little care and adjustment.

An illustration of the Beck lamp mechanism is shown in Fig. 4. Both carbons are rotated for the purpose of keeping surfaces bathed in the inert gas and to keep the arc central and thus promote evenness of burning. The positive holder is fixed, the carbon being fed through it at such a rate that the crater is always maintained at the focus of the mirror; the rate of feed is controlled automatically, a small mirror being placed in the drum which, when the carbon feeds too slowly, reflects a small beam on a thermocouple, and closes a relay circuit which by means of a solenoid quickens the feed. When the carbon is back in focus the small beam of light is off the thermocouple and the feed is slowed down. In addition, the feed may be controlled by hand. The negative carbon feeds through the negative holder in a similar manner, except that the control is by hand. The negative holder is also fixed except when striking the arc, when it is moved up by a striking motor.

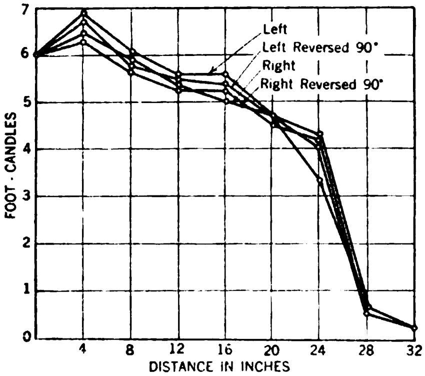


FIG. 3—CONCENTRATED FILAMENT LAMP TEST OF THE NAVY STANDARD 36-IN. SEARCHLIGHT MIRROR TAKEN IN FOOT-CANDLES AT A DISTANCE OF 200 FT.—50 WATT, 6-VOLT, CONCENTRATED FILAMENT LAMP USED

During tests recently conducted on searchlights, the Beck lamp mechanism functioned very satisfactorily; variation of the crater of the positive carbon from the focus was about 1mm. (hardly noticeable) and the arc length was kept practically constant. No trouble in maintaining the arc was experienced while rotating both carbons, the crater of the positive carbon remained even and there was no noticeable hissing and jumping of the arc. On the other hand, while the standard motor-controlled lamp mechanism functioned successfully, maintaining practically a constant voltage, the arc length did not remain constant and the positive crater did not remain at the focus, due to the impracticability of constructing positive and negative carbons which will be consumed at a certain given ratio. Also the positive crater tended to wander over the surface of the positive carbon with the result that one side would project and the other recede causing a hissing arc and making it necessary, in order to obtain any consistent results, to shut off the light and turn the positive carbon by hand about every 15 or 20 minutes.

We now come to the arc, probably the most important part of the searchlight and also the one least understood. There have been numerous treatises written on the arc, but it has been always discussed from the general illuminating side and without much consideration of its uses for searchlights. Paragraphs have been written in some illuminating treatises on the searchlight arc, but it has in general been given scant attention. This is probably more or less natural, for the authors of these books were not especially interested in searchlights, and, as a rule, had had very little experience with the subject.

The desired searchlight arc should excel in the following particulars:

1. Small positive carbons with high current densities and thus high crater temperature throughout crater area, which gives high intrinsic brilliancy. Intrinsic brilliancy is the luminous intensity per unit area.

2. Small negative carbons.

3. Long arc length, that is, distance between positive crater and negative point.

4. Uniform mixture of carbon so as to help the evenness of burning.

The Beck searchlight may be considered as being especially designed to meet the above requirements and therein lies its marked superiority over the searchlights now in use.

In a searchlight the angle of dispersion is directly dependent on the diameter of the source of illumination, provided the focal length is constant, and if the diameter of the source can be decreased one-half while the candle power remains constant,

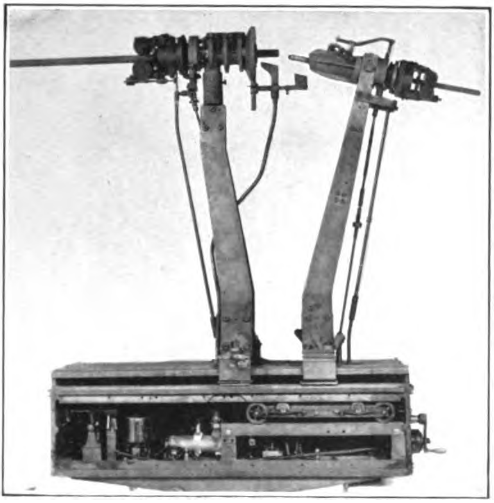


FIG. 4 [MCDOWELL]

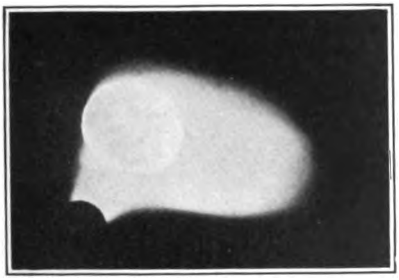


FIG. 7 [MCDOWELL]

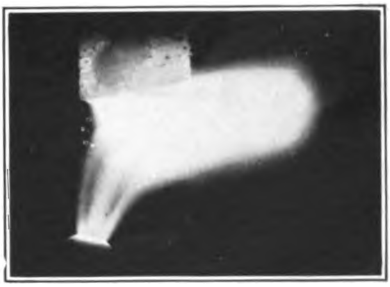


FIG. 8 [MCDOWELL]

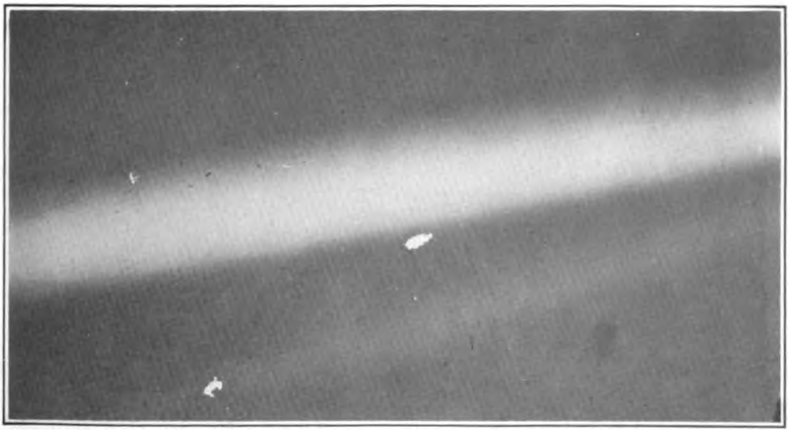
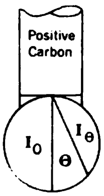


FIG 9 [MCDOWELL]

the intensity of light on the target would be quadrupled. Actually in the Beck light, the positive carbon is reduced one-half and at the same time the candle-power is increased so that greater efficiencies are obtained.

To illustrate the effect of arc length on candlepower it may be stated that with a circular plane radiator (the crater of the positive carbon approximates such a radiator) the maximum candlepower is obtained on the vertical axis of the radiator as shown by the sketch. Here we have I_0 = maximum intensity, and $I_\theta = I_0 \cos \theta$. Thus the smaller the angle the greater the maximum intensity of light falling on the mirror. With positive and negative carbons of a fixed diameter the angle θ depends upon the arc length, being the angle of partial shadow on the mirror projected by the negative carbon cutting off through this angle the light rays emitted by the positive carbon. This may be more clearly expressed by the formulas



$I_\theta = I_0\, q \tan \theta$ where I_0 = the normal intensity as before.

I_θ = the intensity at any angle θ from the normal and

$q = \dfrac{\pi r^2 - S}{\pi r^2}$ where r = radius of positive carbon and

S = the area of overlap of the negative on the positive for the angle θ.

The light intensity is reduced by the shadow of the negative carbon only for those angles of θ which are smaller than

$\tan \theta = \dfrac{r + r_l}{l}$, where

r = radius of positive carbon,

r_l = radius of negative carbon,

l = arc length.

Thus it is seen that to decrease the angle of shadow it is necessary to increase arc length or decrease the diameter of negative carbon. The arc length is restricted to the stability point of burning.

In Fig. 5 is shown by curve the increase of candle power with increase of arc length; the candle powers are taken at 40° from the normal to arc surface and are approximately the maximum.

The arc length of the Beck lamp is maintained constant at about $\frac{7}{8}$ in. as compared to about $\frac{5}{8}$ in. obtained at 60 volts in the standard 36-in. lamp.

Fig. 6 shows the variation of arc voltage with arc length as determined on a set of ordinary 36 in. carbons with constant current of 110 amperes.

It is, of course, well known that carbon is the most refractory of all known materials, boiling at about 4000 deg. cent., but it unfortunately commences to evaporate at a much lower temperature (about 1800 deg. cent.), so that in an ordinary arc very little of the total area of the end of the positive carbon is at the melting temperature, a small wandering spot being the real efficient part of the carbon, and the rest of the end of the carbon is consumed at a much lower temperature, giving off less intense rays and a longer wave length. This may be readily seen in comparison of the Beck and ordinary arc by the color of the arc.

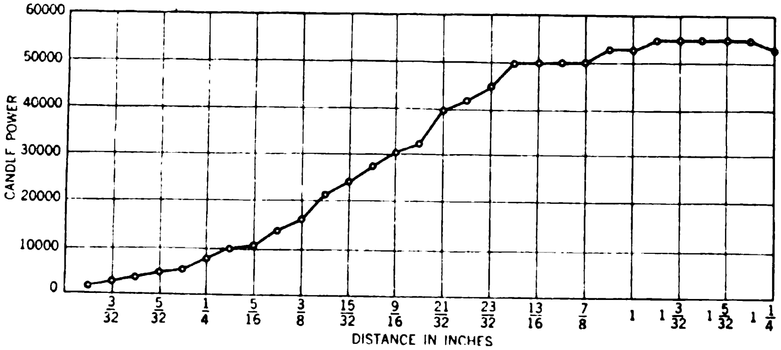


FIG. 5—CANDLE POWER-ARC LENGTH CURVE TAKEN AT A POINT 40 DEG. FROM NORMAL TO THE ARC SURFACE—NAVY STANDARD CARBONS —CURRENT NORMAL 110 AMPERES

In the Beck arc the ends of the positive and negative carbons are enveloped in the hydrocarbon vapors which prevents the consumption of the carbons at a lower temperature, by keeping oxygen from them, in addition it cools the outer shell of the carbons, the gas being at a temperature of about 1000 deg. cent., and thus concentrates the current in the center of the carbons thus a current density greater than 0.75 amperes per sq. mm. is obtained, and the total crater of the positive carbon reaches a very high temperature. The current is brought to both carbons near the ends by roller contacts so the only part having this high current density is the part protected by the indifferent gas. The positive carbon is cored with a rare earth with a melting point at about 3500 deg. cent. The positive develops a deep crater, about 12 mm. deep, filled with incandescent gas. The sides of this crater reflect the light radiation to the focus of this crater and in addition, the light from the negative is reflected, so it is believed nearly true black body radiation is obtained; and by adjusting the focus of the crater to focal point of the mirror the high peak in the luminosity curve of the beam is thus accounted for.

The area of the Beck positive carbon is 201 sq. mm., the area of the ordinary 36-in. light positive carbon is 805 sq. mm. In the Beck light the maximum intrinsic brilliancy is greater than 438 c.p. per sq. mm. The intrinsic brilliancy of an ordinary carbon arc varies from 120 c.p. per sq. mm. to 160 c.p. per sq.mm.

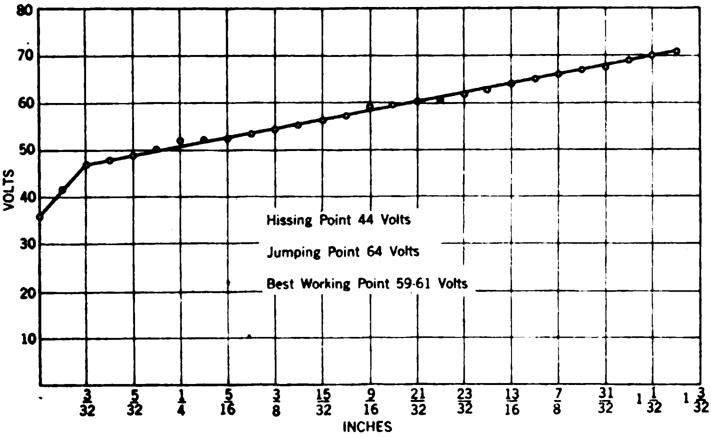


FIG. 6—ARC VOLTAGE-ARC LENGTH CURVE—NAVY STANDARD CARBONS USED—LINE CURRENT CONSTANT AT 110 AMPERES

In addition to the black body radiation obtained from the crater, there is evidently a large amount of light radiated from the incandescent gas in the crater, of a selective nature. It would probably at first be thought that this gas should follow Kirchhoff's laws and absorb the lines which they naturally radiated, giving the Fraunhofer lines seen in the sun's spectrum, but in this case the incandescent gas is at a higher temperature than the crater and the spectrum shows positive lines apparently superimposed on the regular temperature radiation.

It is noticed that taking the Beck carbons and starting at a low current density a luminous arc stream as of a typical white flame arc is obtained, the anode being convex. As the current density is increased the anode becomes concave and the anode stream disappears, apparently being confined to the crater of the positive carbon, leaving only the lower temperature and less luminous cathode stream. The temperature of the incandescent gas within the positive crater is estimated to be between 5000 and 5500 deg. cent. Two views of the Beck carbons burning with normal current densities are shown in the illustrations, Figs. 7 and 8.

For the luminous power J_l, which reaches the eye of the observer, we have the following equation:

$$J_l = \frac{J}{L^4}(1 - P)^{2L} K$$

J = Luminous power of the searchlight.
L = Distance of illuminated object (under the assumption that the observer is near the searchlight).
P = Absorption by the atmosphere.
K = The coefficient of reflection of the illuminated object.

Thus if we assume that a searchlight of certain illuminating capacity makes it possible to easily distinguish an object at 4000 meters, than a searchlight of four times the illuminating capacity will carry 5300 meters, assuming that the absorption of the atmosphere is 10 per cent per kilometer and that the object is equally well distinguished in each case.

It is very hard to compare two searchlights by the eye, but during the test conducted, both searchlights were lighted (Beck and Navy 36-in.) and first one and then the other was turned on the same object with the result that objects not distinguishable, except in a hazy way, with the Navy 36-in. were plainly outlined by the Beck light. It is apparent to the eye that the Beck light is more of a bluish white light than the standard; the ordinary searchlight beam looks yellow in comparison. The aggregate quantity of blue and violet rays in the Beck beam is about 23 per cent. At low intensities of illumination the maximum sensation to the eye for the same strengths of illumination shifts toward the blue end of the spectrum, while at higher intensities of illumination the maximum sensation for same strengths is toward the yellow part of the spectrum. This shifting of the relative sensations for different intensities of illumination is a well known phenomenon called the Purkinje effect. It is thus seen that the Beck light is particularly good for picking up distant objects where the illuminative intensity would be small.

It is also a well known fact that a colored body reflects the colors from the rays falling on it which the body itself contains, and absorbs the rays which it does not contain; the Beck light being strong in the short waves of light would thus be particularly effective in picking up objects of a bluish color, such as the various classes of ships painted bluish gray.

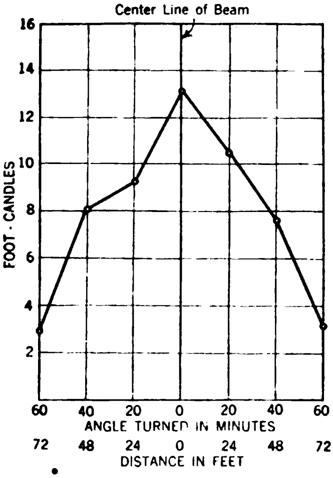


FIG. 10—FOOT-CANDLE POWER-DISTANCE CURVE OF THE BECK 44-IN. SEARCHLIGHT TAKEN AT A DISTANCE OF 2850 FT.—LAMP BURNING NORMALLY

An illustration is shown, Fig. 9, of the Beck light and of a standard 36-in. searchlight, the upper beam being that of the Beck light and the lower of the standard light.

Comparative night illumination tests were conducted between standard 36-in. and 60-in. searchlights and the 44-in. Beck searchlight. The Beck searchlight beam was a more concentrated beam than that obtained from either the 36-in. or 60-in. beam of the standard lamp and the color of the Beck beam was a whiter one than that obtained from the Navy standard 36-in. and 60-in. searchlights. With the carbons burning in a normal condition and placed in the proper focal centers of their respective mirrors, foot-candle-power readings at intervals of 24 ft. were

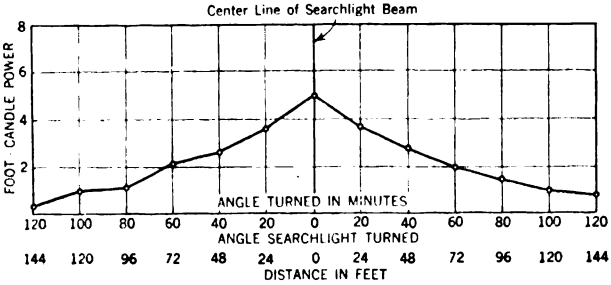


FIG. 11—FOOT-CANDLE POWER-DISTANCE CURVE OF THE NAVY STANDARD 60-IN. SEARCHLIGHT TAKEN AT A DISTANCE OF 2850 FT.—LAMP BURNING UNDER NORMAL CONDITIONS

taken across the beam at a distance of 2850 ft. from the searchlights. Figs. 10 and 11 show the illumination across the beam of the Beck searchlight compared with the 60-in. standard searchlight. From these two curves it can be seen that the maximum illumination obtained from the Beck light is approximately 2½ times as great as that obtained from the standard 60-in. In the Beck searchlight the beam shows a very high illumination at the center and falls off very rapidly at the edge of the beam. The other figures, 12 and 13, were obtained in comparing the Navy standard 36-in. searchlight with the Beck light. The figure containing the results of the 36-in. standard searchlight consists of five curves; the curves indicated by 1, 2 and 3, are plotted from actual results obtained; curve 4 is a resultant of curves 1, 2 and 3, and curve 5 is obtained if a 44-in. Navy standard searchlight is used in place of a 36-in. light. The other figure with the results obtained from the Beck light contains 4 curves; 3 plotted from the actual results obtained, and curve number 4 is the resultant curve of these three. From the comparative data obtained, it can be seen that the illumination obtained with the Beck searchlight is about five times as great as that obtained from

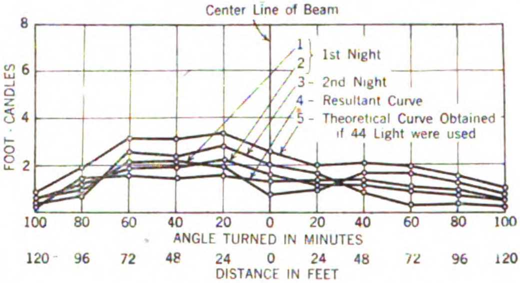


FIG. 12—FOOT-CANDLE POWER-DISTANCE CURVE OF THE NAVY STANDARD 36-IN. SEARCHLIGHT TAKEN AT A DISTANCE OF 2850 FT.—LAMP BURNING UNDER NORMAL CONDITIONS

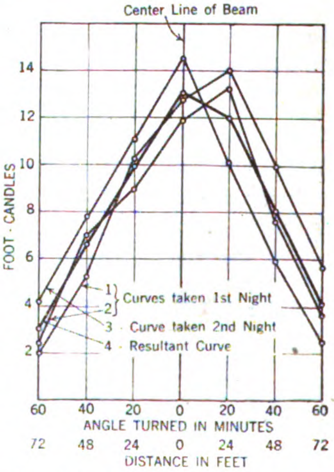


FIG. 13—FOOT-CANDLE POWER-DISTANCE CURVE OF THE BECK 44-IN. SEARCHLIGHT TAKEN AT A DISTANCE OF 2850 FT.—LAMP BURNING UNDER NORMAL CONDITIONS

the standard light. The spherical candle power of the Beck arc was measured and the results obtained are shown in Fig. 14. The maximum candle power obtained with the use of our present Navy standard carbons is 45,000 candle power, as

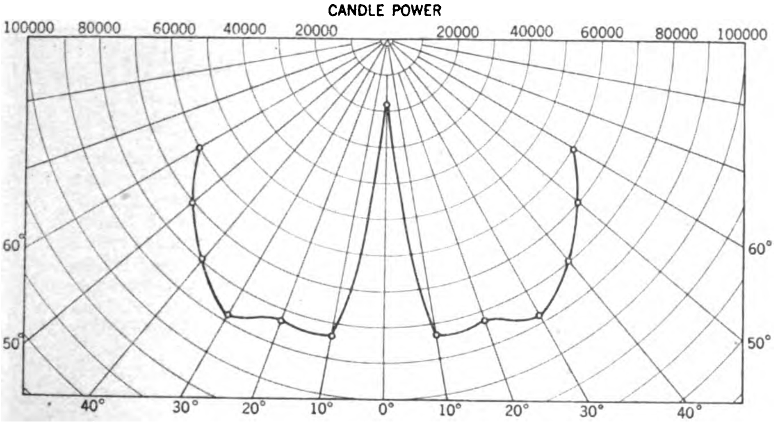


Fig. 14—Spherical Candle Power Curve for the Beck Searchlight Lamp

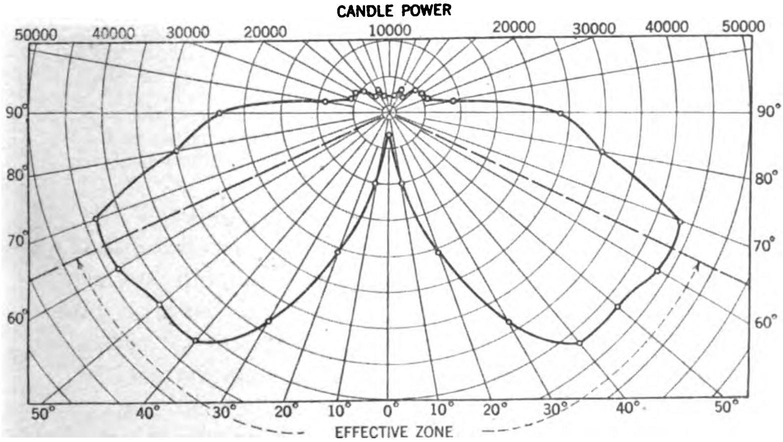


Fig. 15—Candle Power Distribution Curve of Navy Standard Carbons—Line Current 110 Amperes—Arc Voltage 60 Volts—Arc Length Constant at 19/32 in.

against 88,000 candle power obtained from the Beck lamp. A zonal candle power curve of standard 36-in. carbon arc with arc voltage at 60 volts is shown in Fig. 15.

The results shown in Figs. 10, 11, and 13, are relative only, and cannot be used to determine the zonal candle power of the beam reflected from the mirror. The absorption of the atmosphere would have to be taken into consideration to obtain the actual candle power of the beam; the results obtained in Germany with this same light were much higher than those shown here, but the relative intensities between the ordinary arc and the Beck arc were approximately the same.

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 18, 1915, under the auspices of the High-Tension Transmission Committee.

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A 100,000-VOLT PORTABLE SUBSTATION

BY CHARLES I. BURKHOLDER AND NICHOLAS STAHL

Abstract of Paper

Expanding needs of the Southern Power system, paralleled many miles by railroads, required a flexible-connection transformer relay of large capacity, easily portable, and self-contained on a single car. The equipment in operation is of 4000 kv-a. actual capacity, and provided with high- and low-tension switch gear, instruments, panel, wiring and cables, oil-insulated, self-cooled transformers with motor-driven blower for forced air draft, special means of establishing the high-tension delta with 100,000-volt clearances, after transformer terminals and high-tension switches have been raised by a portable derrick, from receptacles where all fragile parts are protected from malicious tampering. Besides meeting standard freight car requirements for transportation, substantial, specially braced trussed superstructure is provided for supporting cabs and switch gear, which latter, as well as transformer terminals, must be lowered, during transit, to meet railroad clearances. Unusual flexibility of voltage connections is secured, contributing largely to the successful operation.

Current for lights, instruments and blower motor is obtained from auxiliary transformer windings incorporated with the main units.

Low-tension arrangements allow operation at various voltages with minimum switching.

The entire equipment is designed for simplicity and dispatch in disassembly for transit, and reassembly in new location.

IN JULY, 1914, there was put into service on the system of the Southern Power Company, a portable transformer substation, unique in several respects, particularly so in the actual capacity of 4000 kv-a. and in the adaptation of the apparatus for operating voltages as high as 100,000.

The idea originated from the growth of the Southern Power Company, the need for some means of extending, at will, the connections of the system, and the somewhat unusual transportation facilities along its transmission lines.

At present, about 1000 miles of 100,000-volt circuits are in operation, with nearly 550 miles more of 44,000-volt lines, besides perhaps 90 miles at 13,200 volts and the regular distribution circuits at 2200 volts. The high-tension circuits are

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connected in the multi-meshed network shown on the map, Fig. 1. The connected transformer capacity, step-up and step-down, is approximately 365,000 kv-a. Closely parallel to these circuits run, for an aggregate distance of about 700 miles, one or more of the following railroads: Southern, Seaboard Air Line, Atlantic Coast Line, Piedmont & Northern, and Clinchfield, thus offering a tempting opportunity, denied to transmission systems remote from railroad facilities, for the use of a portable substation equipped to serve a variety of purposes, especially as the territory served contains many mills and towns along the right of way, where sidings are available.

FUNCTIONS

Such a station must be capable of supplying adequate transformer relays for the following uses:

1. Spare capacity for even the largest stations.
2. Temporary replacement of a distributing or tie-in substation being enlarged or rebuilt.
3. Break-down replacement of a substation.
4. Emergency stand-by service to or from neighboring transmission companies, central stations or isolated plants.
5. "Pioneer service" at town or mill, pending the determination of the proper permanent substation equipment.
6. Tentative service for mill or other prospective customer.
7. "Power solicitor service" with those needing power immediately.
8. Miscellaneous emergencies.

REQUISITE CHARACTERISTICS

To perform these functions satisfactorily, the equipment must (*a*) admit of transport over standard steam and electric railways, *i.e.*, not exceed the limiting dimensions and weights involved in passage through tunnels, over bridges or under tracks; (*b*) make such parts as would, in service, extend beyond railroad clearances, capable of easy and rapid disassembly and, after transport, similar reassembly ready for operation in the new location; (*c*) insure obtaining suitable nominal voltage for both transmission and distribution circuits; (*d*) admit of varying these nominal voltages by moderate gradations to meet line-drop conditions at various places; (*e*) furnish suitable high- and low-tension switch gear, instruments and metering devices; (*f*) protect fragile parts from damage by malicious mischief,

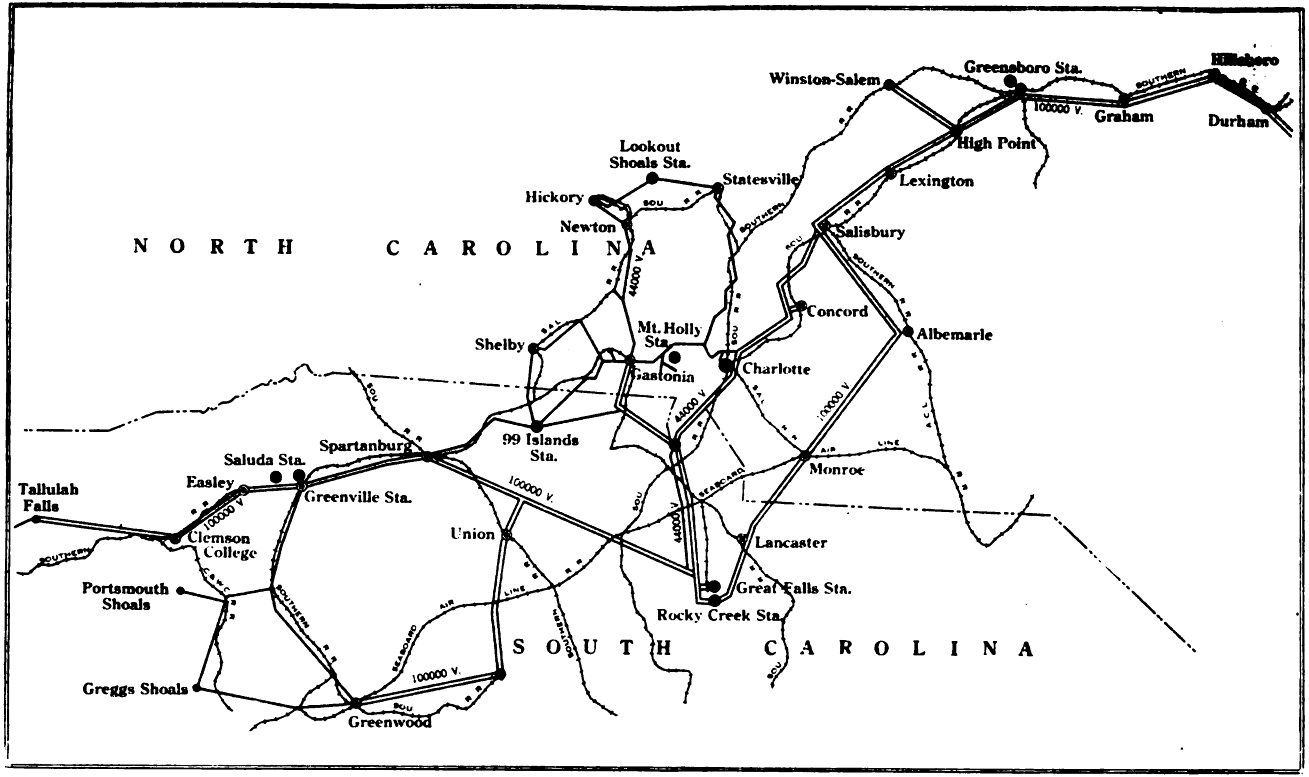


FIG. 1—TRANSMISSION SYSTEM OF SOUTHERN POWER CO.

while in transit or unattended during out-of-service periods; (*g*) carry all accessories for a self-contained unit, such as lifting devices for extensible parts, spare breakable apparatus, etc.; (*h*) conform to requirements of Interstate Commerce Commission for freight car service.

The problem of combining these characteristics to perform the desired functions found its chief difficulties of solution in carrying safely on a single car the weights incident to such high-powered apparatus, and insuring the necessary clearances for the high-voltage circuits; the successful solution is due in large measure to Mr. George N. Lemmon for the treatment of the various parts so as to render unnecessary any changes after installation.

The question of weight involved symmetrical loading of the car without prejudice to the workability of the apparatus, while proper clearances for 100,000-volt circuits within the space limitations of a single car (an essential criterion established by the operating company) made necessary the choice of air-break switches of the horn type with wide spacings from pole to pole, and horns located above other apparatus to allow the arcs to clear.

DESCRIPTION OF EQUIPMENT

General Arrangement. Three 1000-kv-a. transformers, three high-voltage horn gap switches, and two enclosed cabs, are arranged alternately along the length of the car, and occupy the entire floor space except for a railed-in walkway for trainmen at one side. Each transformer weighs 29,000 lb., and one is located over each truck, with the third placed near the center. Six built-up steel columns, with latticed struts, guy rods, and cross bracing provide supports for the high-voltage switches, and also form a rigid framework to which the cab sheathing, the oil switches, and the switchboard are attached. See Figs. 2 and 3.

The principal dimensions of the car are:

Length over sills	38 ft. 0 in.
Width over sills	9 ft. 0 in.
Truck centers	26 ft. 0 in.
Height from top of rail to car floor	3 ft. 7 in.
Wheel base of each truck	5 ft. 2 in.

The trucks are diamond truss type, M.C.B. standards, capacity rating 120,000 lb. exclusive of car. The main framework consists of two center sills of 15-in., 55-lb. channels reinforced by 3-in. by 3-in. angles, and extending the whole length of the car, 38 ft. End and side sills are 12-in., 40-lb. channels with side truss rods. Bolsters are built up of plates and angles. Cross beams are 6-in., 8-lb. channels. The floor is ¼-in. steel plate. Cross beams are arranged in pairs to suit the holding-down bolts of the transformers, which are thus secured directly to the car frame.

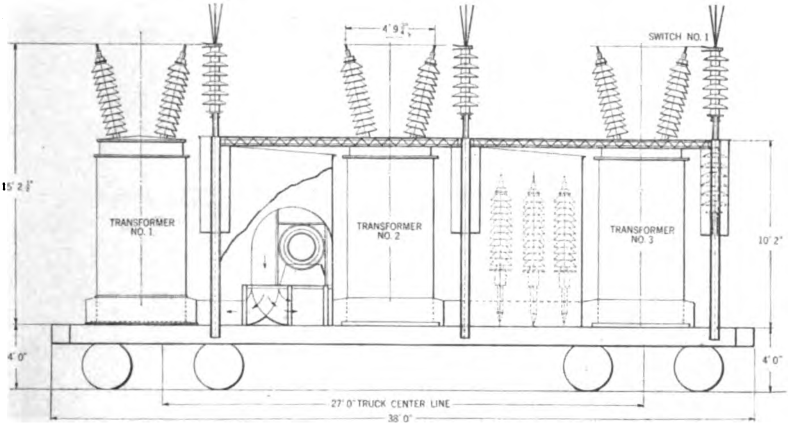


Fig. 2—Substation Elevation

Buffers, draft-gear, air-brakes, springs, journal-boxes, and axles are provided to accord with standard M.C.B. requirements, as well as the wheels of 33-in. diameter and standard tread. The steps, grab-handles and hand-brakes are of the standard freight car type.

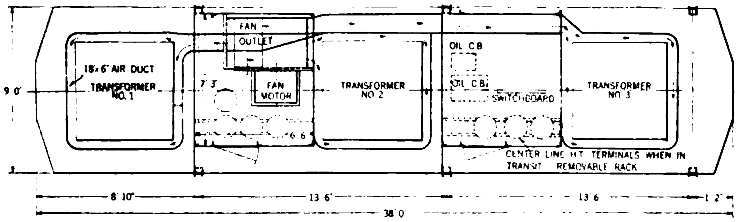


Fig. 3—Substation Plan

High-Tension Switches. Three double-break horn-gap switches, specially designed for 100,000-volt service, are arranged transversely on the car, each being carried on a steel base which, to secure proper clearance height for the horns, slides vertically inside the main columns, and can be raised or lowered by means of two small windlasses, operated by men stationed at each side of the car. Simultaneous service operation of the switches is obtained by means of a pipe rod connected to a crank on each switch.

The switch bases slide up and down in guides made of one 7-in. and two 4-in. channels, and each switch has four insulators of the post type, comprising six 14-in. porcelain disks. The blade is of special brass tee, pivotally mounted on the two central insulators, thus giving a break between a pair of horns at each end of the blade, as shown in Fig. 4. The total clearance between the terminals of an open switch is 6 ft. Each insulator weighs 175 lb., the total weight of each unit raised or lowered being 950 lb.

The passage-way for trainmen and operators limited the distance the switches might be lowered, and hence it was necessary to make the horns detachable by simply bolting each horn in position.

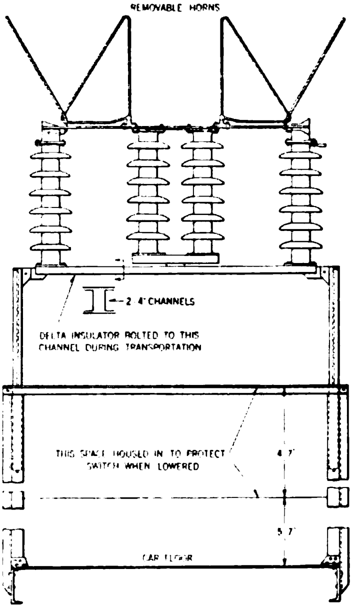

REMOVABLE HORNS
2 4" CHANNELS
DELTA INSULATOR BOLTED TO THIS CHANNEL DURING TRANSPORTATION
THIS SPACE HOUSED IN TO PROTECT SWITCH WHEN LOWERED
4' 7"
5' 7"
CAR FLOOR

FIG. 4—ELEVATION OF HIGH-TENSION SWITCHES AND STRUCTURE

The columns serving as switch guides are braced at the top by latticed struts and diagonal rods with turnbuckles, this structure thus also providing the main supports for the cabs, and the necessary cross-bracing is, in turn, incorporated in the walls of the cabs.

High-Tension Delta. To establish the high-tension delta with sufficient clearance for 100,000-volt operation, the second and third transformer terminals shown in Fig. 8 (counting from the left) are connected directly to the inboard end of the middle switch, while the fourth and fifth terminals similarly connect with the right-hand switch, the first terminal joining the left-hand switch directly, and the delta is closed by bringing to this switch a lead from the sixth terminal by means of two post-type insulators with special bases which hook over the latticed strut so that the insulators lean outwardly at an angle of about 45 deg., and require no bolts for proper support.

Transformers. For obvious reasons, oil-insulated, self-cooled transformers were the only admissible type. Space limitations in height, however, were imposed by tunnel and bridge clearances, and likewise in width both by the necessity for symmetrical truck loading and by the Interstate Commerce Commission requirement of a passage-way for trainmen; similarly in length, by the desirability of keeping down the over-all length of the car, as well as by considerations of normal transformer design, which apply also to undue proportions in the other dimensions.

Thus arose the necessity for provision of additional cooling arrangements, which were secured by a 20-h.p. motor-driven blower having capacity for 20,000 cu. ft. of air per minute at 1 oz. pressure, forcing air from the cab, shown on the right in Fig. 8, through suitable ducts surrounding the base of each transformer, and up along the corrugations. The supply of this air can be regulated by shields or screens at the transformer base. These screens are adjustable in height, acting as valves to the air, which, as experiment shows, closely hugs the corrugations, so that it is not necessary, for adequate cooling, to carry up an enclosing casing further along the sides of the transformer.

A hinged portion of the cab sheathing, which is padlocked shut in transit, is open when in service, and serves as an awning-like protection for the blower intake, while allowing free access of air to it.

To allow transport through tunnels and under bridges, it is necessary to house the transformer terminals, and to lower the lower tension switches. In the case of the transformer terminals, this is accomplished by rigging from the latticed strut structure, forming the top of the frame work above the car, a wooden derrick, the parts of which are carried as car equipment. With this derrick the terminals are lowered through openings in the tops of the cabs, where special steel racks are provided for these terminals, including sheet steel cylinders, which cover the ends of the terminals normally under oil, and prevent the entry of moisture to the condenser type bushings.

Flexibility of Connections. It is possible to secure the following high-tension voltages:

100,000
96,533
93,066
89,600
86,800
86,133
83,333
82,666
79.866
79,200
76,400
73,600
72,933
70,133
69,466
66,666
66,000
63,200
60,400
59,733
56,933
56,266
53,466
52,800
50,000
47,200
46,533
43,733
43,066
40,266
39,600
36,800
34,000
33,333
29,866
30,533
27,066
26,400
23,600
20,133
16,666
13,200

The current-carrying capacity of the windings is such that 28 out of these 42 possible high-tension arrangements can be used with rated capacity output from the transformer (1000 kv-a.) without exceeding, in continuous operation, a temperature rise of 40 deg. cent.

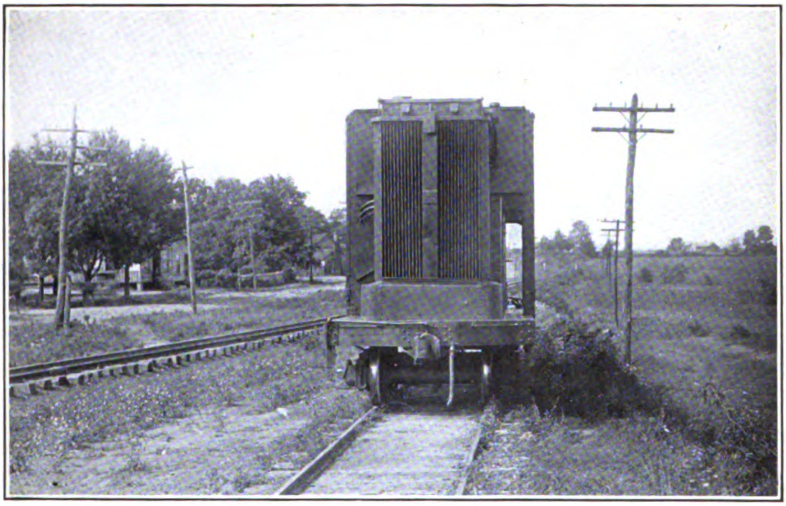
Low-tension windings provide for full capacity output at 2200, 4400, 6600 and 13,200 volts.

Therefore, out of the 168 possible ratios of transformation 112 of these combinations can be secured with full capacity of the transformer.

Auxiliary Transformer Windings. Small lead-covered leads are also brought out from the low-tension sides of the transformers from separate single-phase windings for 110 volts and of 10 kv-a. capacity each, which provide: first, current for the blower motor, regardless of what may be the high-tension or low-tension voltages of the main windings; second, lighting for the car; third, source of voltage for the instruments.

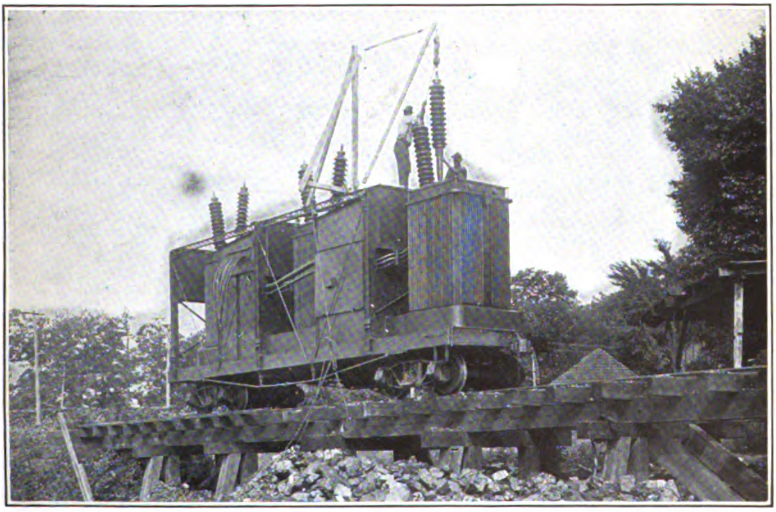
The Low-Tension Delta is established inside the switch cab shown on the right in Fig. 9, the leads being brought by the heavy lead-covered cables indicated, to a point near two switches, the far sides of which are connected together, and jointly feed the outgoing low-tension leads, which pass out of the rear wall of the switch-cab, through porcelain bushings let into a treated wooden terminal block, shielded from drip from the eaves.

Wiring and Switch Gear. High-tension wiring is bare copper. All low-tension wiring is lead-covered cable, the main leads being insulated for 13,200-volt operation, and of sufficient



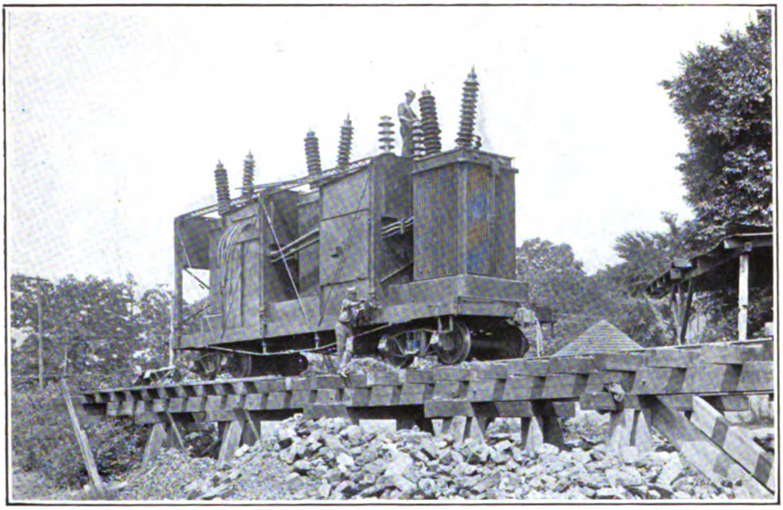
[BURKHOLDER & STAHL]

FIG. 5—CAR DISASSEMBLED FOR TRANSIT—SIDING AT KINGS MOUNTAIN, N. C.



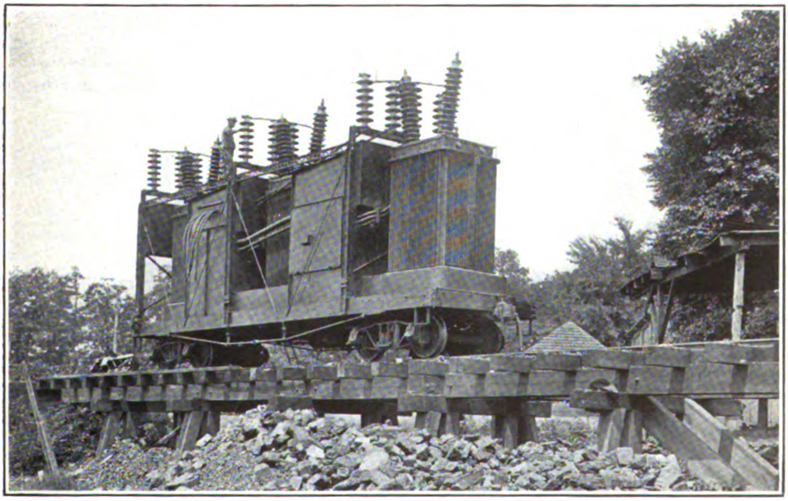
[BURKHOLDER & STAHL]

FIG. 6—CAR IN OPERATING LOCATION, KINGS MOUNTAIN, N. C. LOWERING TRANSFORMER TERMINALS



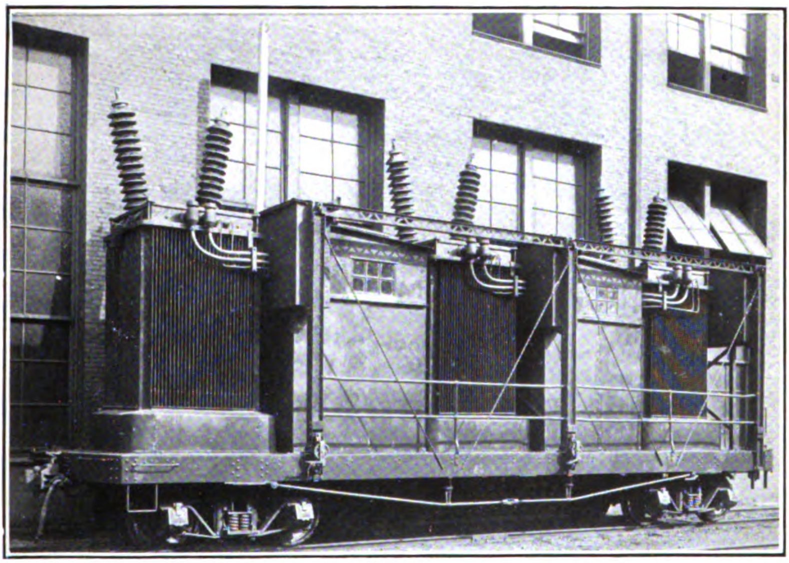
[BURKHOLDER & STAHL]

FIG. 7—HIGH-TENSION SWITCH RAISED INTO PLACE BY WINDLASSES



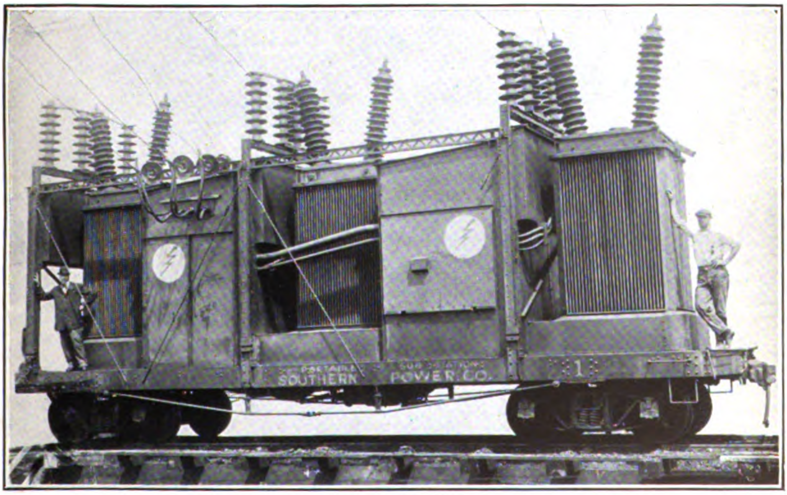
[BURKHOLDER & STAHL]

FIG. 8—HIGH-TENSION SWITCHES AND HORN GAPS ASSEMBLED



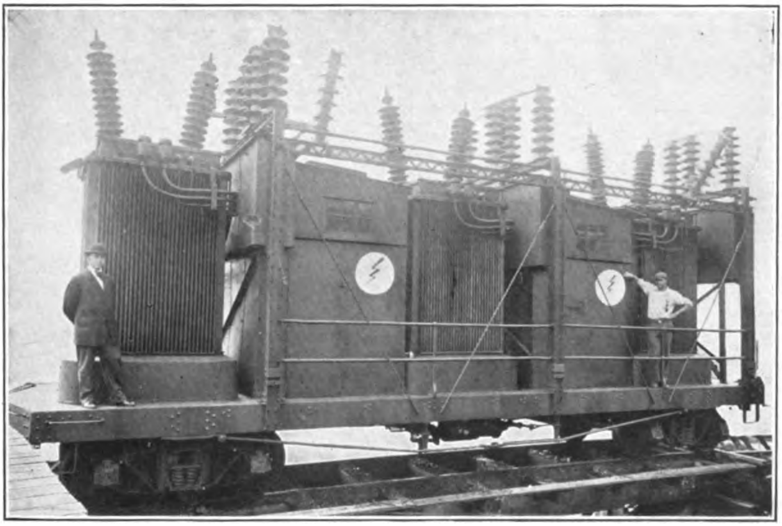
[BURKHOLDER & STAHL]

FIG. 9—VIEW OF CAB ENTRANCES AND LOW-TENSION WIRING



[BURKHOLDER & STAHL]

FIG. 10—SUBSTATION IN OPERATION ON 44,000-VOLT CIRCUIT



[BURKHOLDER & STAHL]

FIG. 11—SUBSTATION IN OPERATION AT HICKORY, N. C. (44,000 VOLTS)

capacity to carry full transformer output when operated at 2200 volts.

Suitable voltmeters, ammeters and watthour meters are mounted on an appropriate panel, also containing the operating handles for the low-tension oil switches.

In order to provide proper metering equipment for the lowest voltage (2200), as well as the highest, (13,200), of the low-tension arrangement, two sets of series transformers are used and so operated from a pallet-switch, mounted on one of the oil switches, that when one of these switches is opened, the corresponding series transformers are short-circuited, and the series transformers for the other oil switch are connected to the metering devices. It was mainly to make "fool-proof" this part of the equipment that two interlocked low-tension switches were provided, both insulated for 13,200-volt operation, and one with adequate current carrying capacity for full output at 2200 volts.

General Comments. The type of steel work selected affords ample mechanical rigidity for stability of operation and transport, and at the same time sufficient flexibility to withstand injury from the rough handling incident to switching operations on steam railroads.

No wood is used in the entire station, except for window sashes, and the outgoing low-tension terminal block.

Special attention was given to the accessibility of all parts and ease of removal in case of accidental damage, as well as to the protection of all parts that might be liable to malicious injury while the station was out of service. In addition to safeguarding the high-tension insulators for both transformers and switches, this includes such items as oil gages, thermometers, oil valves, blower intake, etc.

The total weight of the installation, including car, is approximately 135,000 lb., and the cost of such an installation, complete and ready to run, is approximately $21,000.00, or $7.00 per rated kv-a.

To place the equipment in service, it is first shipped by rail to the most convenient switch or siding, where proper high-tension voltage connections are made on the transformer terminal board reached through a hand hole in the cover. The derrick is then erected and the high-tension terminals are raised out of the cabs, placed in the transformers and connected to the terminal boards. Then the horn gap switches are raised to position and connected to the operating rod, the delta insulators are hooked into place, connections are made between switches and transformer terminals, and the station is ready for connection to the lines. To provide additional room for operators, the racks which support the transformer terminals during transportation can be removed and placed at the back of each cab.

It should be noted that the station is self-contained and all parts of the equipment are transported on the car when in transit.

Fig. 2 gives a line diagram of the apparatus and connections. Figs. 5 to 8 show various stages in the process of placing the station into operation after its arrival on a siding at Kings Mountain, North Carolina, where it replaced a 3000-kv-a. substation undergoing reconstruction. Fig. 9 shows the entrances to the cabs, and Figs. 10 and 11 show the station in actual service at Hickory, North Carolina, connected to the 44,000-volt circuits, and carrying a load of approximately 1000 kv-a.

OPERATION

Although the main transformers are nominally rated at 1000 kv-a. each, test results show heat dissipation such that the station may have an output of 4000 kv-a. without exceeding standard temperature rise. On the same basis the permissible station capacity, without the blower, is easily 2000 kv-a.

The station was first put into commission at Kings Mountain, N. C., and was run there from July 12 until July 26, 1914, connected to the 44,000-volt transmission system, stepping down to 2200 volts, carrying an average load of 2200 kw., consisting of cotton mills and the city municipal lighting and power requirements. At this particular point the permanent substation had become outgrown and it became necessary to rewire and enlarge it. Instead of putting in temporary work, the portable substation was located on an adjacent railway siding and tapped to the main transmission line on the primary side. The various feeders from the permanent station were connected to an outside bus which was in turn connected to the low-tension terminals of the portable substation, thus cutting out the main substation entirely. This work was all done with practically no interruption of service to the city or the manufacturing interests, and permitted the work of rebuilding the permanent station to be done economically and expeditiously.

On the night of July 30th two of the three 44,000-volt transformers permanently installed in the substation at Hickory, N. C., failed during a lightning storm. The portable substation was immediately forwarded to this point and picked up the entire load of the permanent substation at 3.30 a.m. August 4th, and remained in operation until August 27th, carrying an average load of 1000 kw., consisting not only of cotton mill requirements, but also of municipal light and power requirements of the city. The permanent substation at this point is located about two miles from the nearest railroad siding. A 2300-volt circuit extended from the permanent station to the mill which was adjacent to this railroad siding. In order to pick up the total load of the permanent substation the top of the 2300-volt line was rebuilt so as to accommodate three 44,000-volt conductors, and the 44,000-volt line was extended over this line to the railway siding. The portable substation was then connected to this 44,000-volt line, and the 2300-volt circuit was used to transmit current back to the permanent substation and from there distribute it over the regular lines; the 2300-volt line being of comparatively small size, it was necessary to operate at a somewhat increased voltage in order to compensate for the line drop, and in order to take care of the mill immediately adjacent to the portable station two bucking transformers were installed, by which means the voltage for this mill was cut to the proper value.

On August 27, 1914, the substation supplying one of the mills in the vicinity of Winston-Salem was badly damaged by fire and the portable substation was immediately shipped to that point, and the service was restored at 3:30 p.m. on August 30th. The station remained in operation at this point from August 30th until October 18th, carrying an average load of 300 kilowatts. During this run the blower was not used. The supply mains to the mill were 13,200 volts primary and 2200 volts secondary. The portable substation was used in transforming these voltages.

When the station was taken out of service at Winston it was returned to Charlotte and a thorough examination was made not only of the apparatus of the station but also the car as well, and no defects of any nature were discovered.

No difficulties of operation were experienced, and, as a matter of fact, the operation was as reliable and satisfactory as that of the permanent stations would have been.

The station, in addition to the distance from Pittsburgh to Kings Mountain, has been shipped over about 275 miles of railroad in this territory, and no defects of any nature have become apparent.

The housing of the apparatus is of such nature as to make it unnecessary to provide any cover either when in or when out of service. A permanent place of storage has been provided for this station in the railroad yards at Charlotte. It is not necessary, however, that the station be stored where constant watchfulness can be exercised, as it is so well housed that it is practically impossible for anyone, so inclined, to meddle with it.

Notwithstanding the conflicting requirements of such a station, and the varied functions it is called upon to perform, the test of experience has demonstrated the adequacy of design, and yielded an operation eminently satisfactory.

To be presented at the 3d Midwinter Convention o the American Institute of Electrical Engineers New York, February 18, 1915, under the auspices of the Electric Lighting Committee.

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DIMMERS FOR TUNGSTEN LAMPS

BY ALFRED E. WALLER

ABSTRACT OF PAPER

The advent of tungsten lamps for theatre lighting made necessary a complete re-design of the dimming apparatus.

Dimmers designed for the control of carbon filament lamps do not give smooth and flickerless regulation when used with equal loads of tungsten lamps. This is due to the temperature coefficient of resistance of the lamp filaments, that of the carbon filaments being negative, and that of the tungsten filaments positive.

Curves are shown to indicate the change in lamp resistance and candle power for various watt inputs. Curves for both carbon and tungsten filament lamps are shown in order to bring out the contrast, and a method described for determining the resistance per step and number of steps in the dimmer designed for control of tungsten lights.

Following is a brief indication of commercial requirements in dimmer design.

ONE OF the changes brought about by the introduction of tungsten lamps has been a complete redesign of the apparatus used for lamp dimming in theatrical work.

At the time when tungsten lamps first came into general use the design of theatre dimmers for carbon lamps had become fairly well standardized. A rheostat with 50 steps of resistance, and a taper of approximately 5 to 1 in ampere capacity had been found entirely adequate and satisfactory, and this design was practically universal.

The controllers, or dimmers, to use the trade name, which were built to regulate the illumination of carbon lamps were found unsatisfactory, however, when the carbon lamps were replaced by lamps having metallic filaments such as tungsten. Metallic filaments have a positive temperature coefficient of resistance, while carbon filaments have a negative temperature coefficient of resistance. For instance if we start with two filaments of the same resistance, one of carbon and one of tungsten and raise them to incandescence, the tungsten filament at its full incandescence will have thirty-five times the

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Manuscript of this paper was received April 3, 1914.

resistance of the carbon filament at its full incandescence. On account of this disparity, the control of tungsten lamps by dimmers designed for carbon lamps was uneven, the lights flickered considerably, and, in some cases it was found that desirable lighting effects obtained in the past could not be duplicated.

A comparison of the resistance characteristics of the carbon and tungsten filaments in actual operating conditions served to indicate the reason for this difficulty, and it is by reviewing this comparison that the problem may be most readily understood.

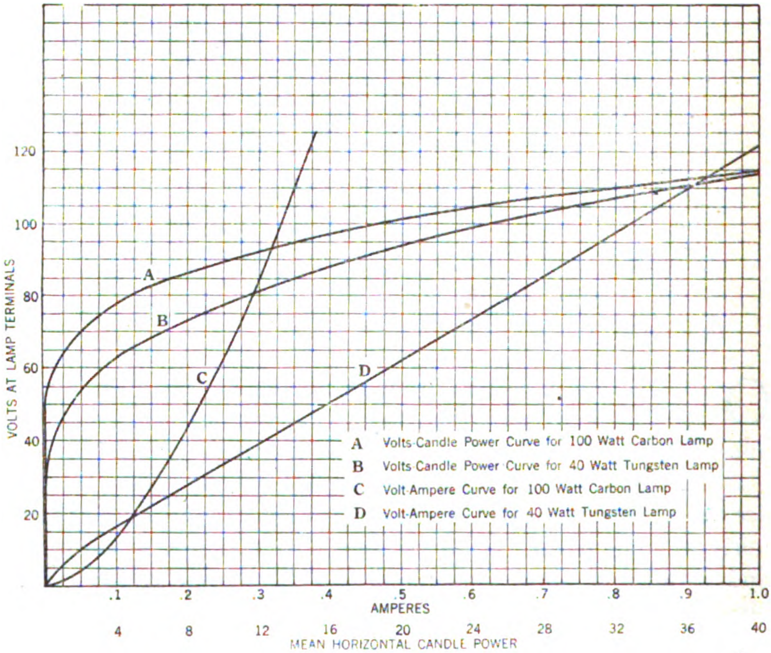


FIG. 1

The curves shown in Figs. 1 and 2 were plotted from a table of readings obtained by varying the potential at the terminals of a test lamp, in two-volt steps from zero to 126 volts, and recording the amperes flowing and candle power emitted at each step. The lamps used were a 40 watt tungsten, and a 100 watt carbon filament lamp, both rated at 110 volts. These were selected because their candle power at full voltage is practically the same, and an opportunity is thus afforded to compare the dimmers required for controlling installations of either type having approximately the same total candle power.

The design of a dimmer for carbon lamps is a comparatively simple matter. It will be noted that curve *A*, Fig. 2, which is that of a carbon lamp, has very little inclination between the 10 watt and 100 watt abscissas. This indicates that there is little change in resistance of the carbon filament between these points, which represent approximately the practical working range of the lamp. In order that the lamps when in use may be totally extinguished without opening the circuit, it is customary to build the dimmer with enough resistance to reduce the input somewhat below 10 watts, or, in the case of this particular lamp to approximately 6 watts. At this input, which is attained at 28 volts, the filament is at "visible red"—that is, it may be distinguished as a faint red line, if kept in a perfectly dark room. Not until the applied voltage is 48 volts do we obtain one tenth of one candle power.

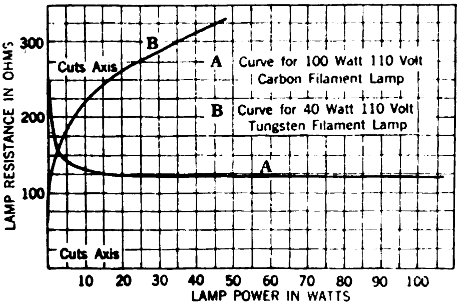
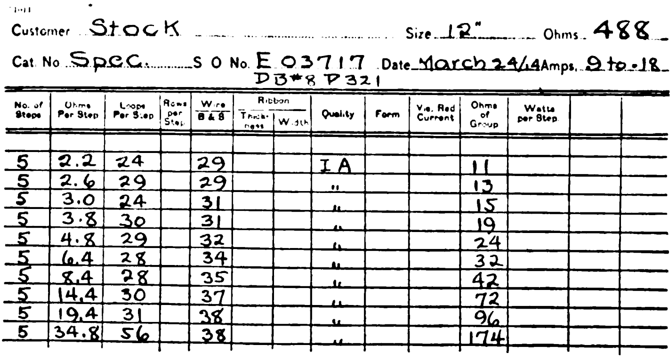


FIG. 2

The calculation of the resistance per step of a dimmer for this type of lamp would be similar to the computation of a generator field rheostat, or any other controller designed for operation in series with a substantially constant resistance across a constant supply voltage. The full rated current of the lamp is 0.9 amperes, the minimum to which we will reduce this by means of the rheostat, 0.18, the line potential 110 volts, and the working resistance of the lamp 122 ohms approximately.

At the minimum current of 0.18 amperes the lamp resistance is actually 138 ohms, but the increase in resistance takes place after the lamp has, so to speak, ceased to exist as an illuminant, and for this reason, in designing it is convenient, and entirely satisfactory to assume the resistance as constant at 122 ohms. The only effect which this assumption has on the design is to increase the resistance of the rheostat slightly beyond what is absolutely necessary, thus permitting the " dimming out" mentioned in a previous paragraph. It may be noted at this point that dimming to visible red is not usually necessary. The general requirement is met by a dimmer which will reduce the illumination to a point where it is no longer perceptible on the stage.

A typical data card of a carbon filament dimmer is reproduced in Fig. 3. The steps of resistance are divided into groups, as will be noted, for convenience in manufacture. This does not in any way alter the correct operation of the dimmers; if the steps are calculated one at a time it will be found that those adjacent vary by amounts too small to be taken into account in this kind of work. The change in resistance per step when we proceed from one group of steps to the next becomes insignificant if we compare the resistance of the step with the total amount of resistance then in circuit.



Customer Stock Size 12" Ohms 488

Cat. No. Spec. S O No. E 03717 Date March 24/14 Amps. 9 to 18

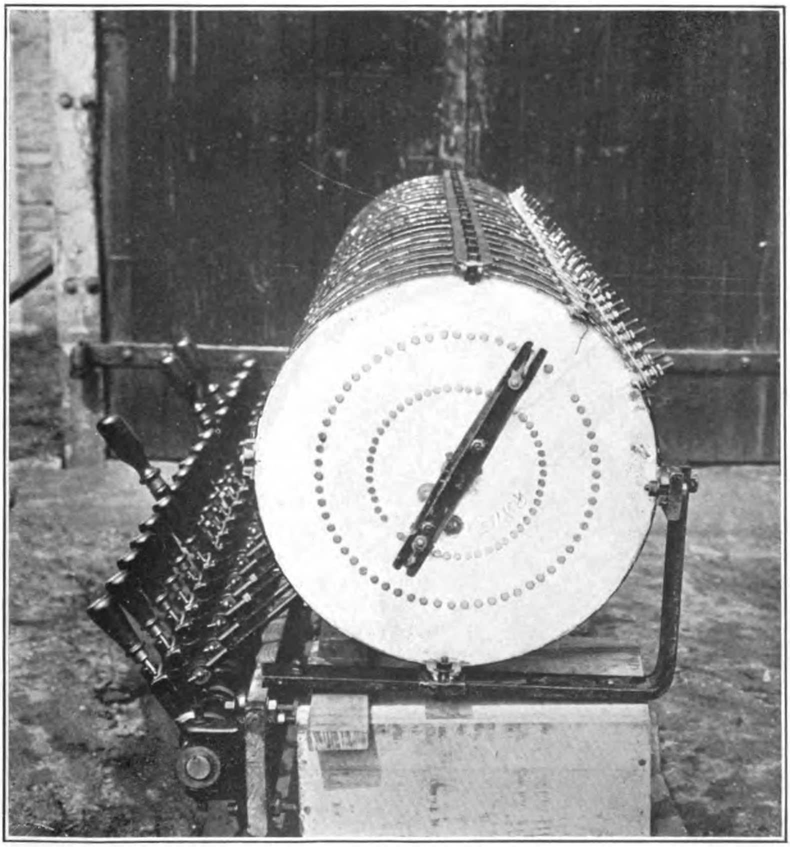
DB*8 P321

No. of Steps	Ohms Per Step	Loops Per Step	Rows per Step	Wire B & S	Ribbon Thickness	Ribbon Width	Quality	Form	Vis. Red Current	Ohms of Group	Watts per Step		
5	2.2	24		29			I A			11			
5	2.6	29		29			"			13			
5	3.0	24		31			"			15			
5	3.8	30		31			"			19			
5	4.8	29		32			"			24			
5	6.4	28		34			"			32			
5	8.4	28		35			"			42			
5	14.4	30		37			"			72			
5	19.4	31		38			"			96			
5	34.8	56		38			"			174			

FIG. 3

In preparing a card such as is shown in Fig. 3 it is assumed that as each group of steps is cut into circuit it will reduce the current by 1/nth of its normal value, where the number of groups is n. By calculating the total ohms in circuit at each required current, and subtracting each total amount from the value succeeding, the resistance of each group of steps is obtained.

It is interesting to note that the negative temperature co-



[WALLER]

FIG. 5—THEATER DIMMER FOR TUNGSTEN LAMPS

efficient of a carbon filament produces a change of resistance which supplements the action of the dimmer, whether the light is being raised or lowered. For instance, let us assume that the carbon filament lamp is burning at half normal candle power and is to be dimmed still lower. If another step of the rheostat resistance is cut into circuit, the current flowing will be reduced, the filament will at once become cooler and will increase in resistance, this increase causing a further slight decrease in the current. Conversely, when any portion of the rheostat is cut out of circuit we have an increase in current which raises the temperature of the filament, and the corresponding decrease in its resistance allows as lightly greater current to pass, just as if another step of the rheostat were cut out of circuit. In this manner, the carbon filament acts to assist the dimmer, step by step through the entire range of control. Of course this action is very slight through most of the range, for the lamp resistance remains practically constant, as already demonstrated.

In striking contrast with this is the tungsten lamp, which opposes every attempt at control, and must be regulated by much finer divisions of resistance to get flickerless dimming. As in the case of the carbon lamp, let us assume half normal candle power and cut additional resistance into circuit to obtain less illumination.

At 110 volts this tungsten lamp gives 36 candle power, and the 18 candle power mark is reached with 91 volts impressed, and 0.317 amperes flowing. (See curves *B* and *C*, Fig. 1). The lamp resistance at this candle power is therefore 287 ohms. The rheostat resistance in series to give this condition on a 110 volt line is obviously 19 ÷ 0.317 = 60 ohms. If the resistance of the lamp filament remained constant, we could reach quarter normal candle power by inserting 39 ohms additional in circuit, or a total rheostat resistance of 99 ohms. These data are taken from curves *B* and *C*, Fig. 1, where it will be noted that nine candle power is emitted at 76 volts with 0.285 amperes flowing. As a matter of fact, however, the lamp resistance at quarter normal candle power is 266 ohms, so that the total rheostat resistance at this point must be 120 ohms instead of 99, or approximately a 50 per cent greater increase than that which would be necessary with a filament of constant resistance. In the same way, when resistance is cut out of circuit, in order to raise the candle power, it must be reduced at a rate which will compensate for the increase of the resistance of the tungsten filament with increasing temperature.

The shape of curve *B*, Fig. 2, indicates that the tungsten filament changes in resistance throughout the entire working range of the lamp, and, furthermore, that the rate of this change is not constant. Curve *B*, Fig. 2, shows this more clearly than curve *C*, Fig. 1. The last mentioned curve resembles somewhat the parabola $X^2 = 4\,p\,y$, but does not coincide with it.

Evidently, when designing a dimmer for controlling this lamp, we shall not be able to assume a constant value for the lamp resistance, as in the previous case.

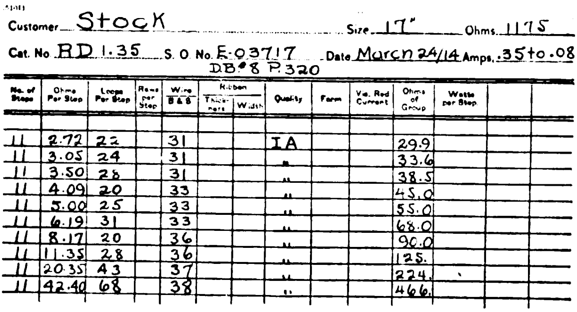
It would be possible, no doubt, to work out the equation of the curve, and make some interesting deductions by means of it, but by far the most convenient method is to obtain various values of resistance from curve *C*, Fig. 1. By calculating the resistance required in series with the lamp at various voltages, the correct resistance for each group and step is readily obtained.

The marked contrast between this lamp and the carbon filament type is more than ever noticeable when we compare curve *B*, Fig. 2, with curve *A*, Fig. 2. The resistance of the tungsten filament at full incandescence is approximately 16.5 times its cold resistance, while the carbon filament at full incandescence, is about one half of its cold resistance. The one tenth of one candle power mark is reached at 48 volts for the carbon filament, and 28 volts for the tungsten filament. The tungsten filament may be made visible red with 10 volts, while 18 volts are required for the carbon filament.

Now, if we assume a constant line voltage of 110 volts, and a dimmer in series with our lamp, we may obtain from curve *C*, Fig. 1, the amperes flowing when different proportions of the line volts are dropped on the rheostat. Tabulating the results thus obtained we have:

Volts on lamp.	Volts on rheo.	Amperes.	Total rheo. resis.	Increment of resis.	Per cent of total resistance.
110	0	0.355	0		
100	10	0.335	29.9	29.9	2.54
90	20	0.315	63.5	33.6	2.86
80	30	0.295	102.0	38.5	3.28
70	40	0.272	147.0	45.0	3.82
60	50	0.247	202.0	55.0	4.68
50	60	0.222	270.0	68.0	5.79
40	70	0.194	360.0	90.0	7.65
30	80	0.165	485.0	125.0	10.63
20	90	0.127	709.0	224.0	19.05
10	100	0.085	1175.0	466.0	39.60

After the characteristics of a suitable rheostat had been obtained as above, considerable experimenting was found necessary in order to determine how many steps, or subdivisions there should be to a group. Some eyes are more susceptible than others to changes in the intensity of light, and in nearly every case the color and form of the illuminated objects, or the back ground, will make an appreciable difference. To cover this point thoroughly, a large number of tests were made before a group of witnesses who independently recorded their observations. In the first rheostat constructed, each of the ten groups or increments in the table was divided into 15 steps, this rheostat was compared, and tested with one having a total of 130 steps, another with 120 steps, another with 110 and a fifth with 100 steps. This last rheostat gave very satisfactory control on a 110-volt line, but it was not considered advisable to use a lower number of steps, as several of the witnesses could detect a slight flicker at certain parts of the range when 90 steps were used. It will be remembered that the tungsten filament begins to glow at 10 volts, and if the dimmer is used to cut down the line volts to this point, there will be 110 − 10 = 100 volts impressed upon it, or in other words, a properly designed 100-step dimmer will regulate to approximately one volt per step throughout the range, if used on a 110-volt line. It is not uncommon, however, to find lines which run to 120 volts or slightly over, and for this reason the tungsten dimmer was designed with 10 groups each of 11 steps, or 110 steps total. The values are given in Fig. 4.



Customer Stock Size 17" Ohms 1175

Cat. No RD 1.35 S. O. No. E-03717 Date March 24/14 Amps. .35 to .08

DB. 8 P. 320

No. of Steps	Ohms Per Step	Loops Per Step	Rows per Step	Wire B & S	Ribbon Thickness	Ribbon Width	Quality	Form	Vis. Red Current	Ohms of Group	Watts per Step		
11	2.72	22		31			IA			29.9			
11	3.05	24		31			"			33.6			
11	3.50	28		31			"			38.5			
11	4.09	20		33			"			45.0			
11	5.00	25		33			"			55.0			
11	6.19	31		33			"			68.0			
11	8.17	20		36			"			90.0			
11	11.35	28		36			"			125.			
11	20.35	43		37			"			224.			
11	42.40	68		38			"			466.			

FIG. 4

The mechanical design was accomplished by using a circular plate 17 inches in diameter, with two concentric rows of contacts as shown in Fig. 5. The contact shoes mounted on the rheostat arm or lever must be noiseless and very smooth running, for flickering of the lights may be produced by uneven contact. Ease of mechanical movement is essential in work of this kind, for the most carefully designed rheostat will not give satisfactory control if the contacts bind or stick, and the contact arm jerks from point to point as the control lever is moved over.

In most theatre installations the dimmers are placed at the top of the switchboard, and, as the number of circuits controlled is sometimes quite large, the size of plate is very important. These 110-step plates may be mounted four inches apart and compare favorably in dimensions with the dimmers for carbon lamps which they are designed to replace. Dimmers for carbon lamps are supplied by well known manufacturers in 18-in. diameter size, and also in rectangular plates 15 by 24 in. and 14 by 14 in.

It will be noted in Fig. 5, which shows a modern type of dimmer installation, for control of tungsten lamps, that each plate has an individual handle. These all interlock at will with cams on the shaft which supports them, and it is possible by means of the master levers to operate any number or all of the plates in unison. The control handles of the bank of dimmers shown in the illustration are mounted on a wooden template for shipment. When the apparatus is installed on top of a theatre switchboard, the bearings of the operating shaft are transferred to the top of the switchboard slate. This makes a convenient and accessible arrangement.

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915.

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ELECTRICAL PRECIPITATION

THEORY OF THE REMOVAL OF SUSPENDED MATTER FROM FLUIDS

BY W. W. STRONG

ABSTRACT OF PAPER

The frictional resistance of a small particle moving through a fluid is given by the law of Stokes. Knowing the density and size of the particles and the coefficient of viscosity of the medium, the amount of energy required to remove suspended matter from fluids can be calculated. From the formulas the relative efficiences of the different methods used to remove suspended matter from gases can be obtained. From these formulas the electrical method is shown to be especially adapted to fine suspended particles or to a mixture of gases that can be selectively ionized. In a practical case of electrical precipitation of smoke it is shown that approximately 4 per cent of the energy of the corona discharge is actually expended in the process of precipitation.

The manner of the distribution of the energy of the corona discharge is discussed. The nature of the corona ionization and the "corona" rays is also briefly described.

The application of the theory of electrical precipitation is given so that it is possible to determine the best working conditions for precipitating a given kind of suspended matter from a given fluid. The theory also indicates the limits of usefulness of the method of electrical precipitation.

THE ENERGY REQUIRED TO REMOVE SUSPENDED MATTER FROM FLUIDS

IN GENERAL it may be said that the engineering problem of removing suspended smoke, fumes or dust from gases and liquids requires that these particles be given more or less velocity. The gases or liquid usually pass through the precipitation chamber with a certain velocity which we will designate as the *longitudinal* velocity. If the suspended matter can be given a *transverse* velocity independently of the velocity of the fluid, we have a way of separating the suspended particles from the fluid. Precipitation is therefore a process of subjecting smoke, fumes or smoke and gases to differential forces. Examples of the action of differential forces are given by "settling" due to

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the gravity forces, the centrifuge process (often applied in flues by the use of sudden changes in the direction of the flue gas current or in fans and centrifuge machines), the separation of suspended matter by the direct action of the electric and magnetic fields, or by the ionization methods as used in the Cottrell and corona methods of electrical precipitation.

In all these methods of precipitating smoke, fumes and dust the amount of energy actually required can be calculated by means of the law of Stokes provided one knows the size (radius of the suspended particles $= a$) of the particles, their density (d), their velocity (transverse velocity V_t), the number of particles (n) per unit volume of the medium and the coefficient of viscosity of the medium (μ).

As a typical example of the precipitation of fumes, smoke or dust let us assume that Fig. 1 represents a cross-section of the precipitation chamber. The length of the chamber is AB or L cm. and the distance between AB and CD is l cm. The longitudinal velocity of the gas through the chamber is V_l. In order that the fumes shall be precipitated it is necessary that they be given a velocity V_t such that they will all be carried to the walls during the time $\left(\frac{V_l}{L}\right)$ required for the gases to pass through the precipitation chamber. It will also be assumed that the particles stick to the walls and this is partly accomplished through electrostatic attraction in the electrical method. Complete precipitation for the chamber represented by Fig. 1 therefore requires the transverse velocity (V_t) to carry the particles to either AB or CD. We may assume that in one half of the chamber the transverse velocity is towards AB while in the other half it is towards CD. (This can be approximated by having an electrically charged plate in the middle of the chamber and charging the smoke particles to an opposite sign.)

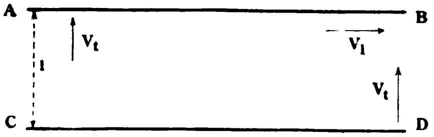

FIG. 1

We have, therefore, $\frac{1}{2}\, l/V_t = L/V_l$ **(1)**

Using a margin of safety of 1.2, we may say $\frac{1}{2}\, l\ V_l = 1.2\, L\ V_t$ or

$$V_t = \frac{l\ V_l}{2.4\ L} = 0.4\ l\ V_l/L \tag{2}$$

Assuming our precipitation chamber to be one cm. thick, the volume of gas passing through the chamber per second is $l\ V_l$ cu. cm., and the number of particles passing per second is $n\ l\ V_l$.

Let E_p be the energy required to carry the particles through the gas with the velocity V_t and give them their kinetic energy which they eventually transfer to the walls of the chamber when they " stick " to it. Let F be the frictional resistance encountered by the particle and s the distance subjected to this frictional resistance. Then

$$E_p = \left\{ \tfrac{1}{2}\, m\ V_t^2 + F\, s \right\} n \text{ ergs per unit volume.} \tag{3}$$

For complete precipitation in the chamber of Fig. 1, and for the treatment of $l\ V_l$ cu. cm. of gas per sec.

$$E_p \text{ in ergs per sec.} = n\ l\ V_l\ (\tfrac{1}{2} m\ V_t^2 + \tfrac{1}{2}\ F\ l) \tag{4}$$

The law of Stokes gives the value of the frictional force F and this law has been found to hold with a considerable degree of accuracy for wide variations in the radius, shape and nature of the particles. This law is:

$$F = 6\pi\ \mu\ a\ V_t\ d. \tag{5}$$

(4) then becomes,

$$E_p \text{ in ergs per sec.} = \tfrac{1}{2}\ l\ V_l\ (m\ V_t^2 + 6\ \pi\ \mu\ a\ V_t\ dl) \tag{6}$$

or,

$$E_p \text{ in ergs per sec.} = \frac{0.2\, l^3\, d\, V_t^2}{L} \left(\frac{0.16\ \pi\ a^3\ V_l}{3\ L} + 6\ \pi\ \mu\ a \right) \tag{7}$$

In the case of smoke and most kinds of fumes and dust a is small. so that the term $\frac{0.16\ \pi\ a^3\ V_l}{3\ L}$ is negligible. It is in this field that electrical precipitation is especially well adapted, since the forces acting on the smoke particles depend upon the number of ions striking the particle and on the charge of the particle. On the other hand, centrifuge forces vary as the mass of the particles and therefore as a^3. For centrifuging, equation (**7**) would remain as stated. For electrical precipitation (**7**) becomes

$$E_p \text{ in ergs per sec.} = \frac{1.2\,\pi\,\mu\,a\,l^3\,d\,V_l^2}{L} \qquad (8)$$

For practical purposes it is convenient to make the precipitation chamber as large as possible, but it is seen from equation (**8**) that this is impossible since l appears cubed. It is also seen that V_l cannot be increased very greatly even though the length of the precipitation chamber is increased. The greatest efficiency is to be attained therefore by making l and V_l as small as is practicable. In practical work, l should not exceed **5** or **6** inches, and V_l should not greatly exceed 8 or 10 feet per second. The maximum values of l and V_l are also limited by the nature of the corona discharge itself, as will be shown later.

The Corona Discharge

The corona discharge consists of an electrical current carried by ions produced by the secondary ionization resulting from the impacts of rapidly moving ions with the gas molecules. For purposes of illustration and for practical electrical precipitation of smoke and fumes, the term corona discharge will be restricted to the use of an electrical discharge, taking place between a wire (placed axially) and its enclosing cylinder. The process of secondary ionization is accompanied by a number of transformations. Let E be the energy consumed in the discharge. Part of this energy is converted into the luminous effects of the discharge, (E_l), part in effecting chemical reactions, (E_c), in heating the electrodes, ($E_{h.e.}$), in heating the gaseous medium, ($E_{h.g.}$). We have then,

$$E = E_p + E_l + E_c + E_{h.e.} + E_{h.g.} \qquad (9)$$

Several of these quantities can be measured separately so that it is to be hoped that our knowledge of these energy changes will soon be greatly extended.

The nature of the ionization taking place during electrical discharges at low gas pressures has been studied by Thomson, Stark and others, and it will be assumed here that the kind and relative number of ions in the " corona rays " and the " corona streams of ions " is the same qualitatively as at low pressures. At atmospheric pressure, however, the ions will be shorter lived, be less simple in constitution and will form less distinct rays, so that the phenomena will not be the same.

The kind of ions that may exist in oxygen and nitrogen for longer or shorter intervals of time are as follows: $\overset{-}{O}_2$, electrons, $\overset{-}{O}$, $\overset{+}{O}$, $\overset{++}{O}$, $\overset{+}{O}_3$, $\overset{+}{O}_6$, –, and charged nuclei. $\overset{+}{N}_2$, –, $\overset{+}{N}_1$, – , $\overset{++}{N}$, $\overset{+}{N}_3$, – , $\overset{+++}{N}_1$, and charged nuclei. Even at low gas pressures many of these ions appear very rarely, so that one may assume the corona ions to consist largely of $\overset{-}{O}_2$, $\overset{+}{N}_2$, $\overset{-}{O}$, $\overset{+}{N}$, $\overset{+}{O}$, possibly $\overset{++}{N}$ and some charged nuclei.

There may be several processes of ionization possible, the process at any place depending on the nature of the gas, the corona rays and the electric field existing there. With increasing field strength the order of appearance of these different types of ionization is probably somewhat as follows:

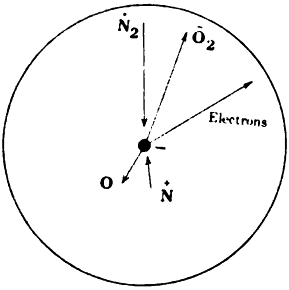

FIG. 2—NEGATIVE CORONA RAYS

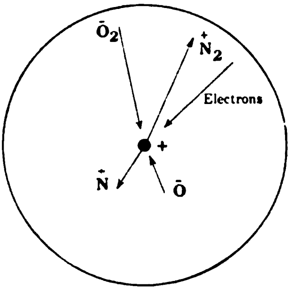

FIG. 3—POSITIVE CORONA RAYS

(*a*) Secondary ionization produced by the natural ions of the gas and by the electrons produced by this ionization. The ions are probably almost entirely of the $\overset{-}{O}_2$, and $\overset{+}{N}_2$ type. As the potential gradient (depending on whether there is a + or −corona) is increased, (*b*), ions like $\overset{-}{O}$ and $\overset{+}{N}$, are formed. The different ions probably begin to ionize by collision for different potential gradients, so that the nature of a corona ray depends on the value of this gradient.

The nature of the corona rays is not well known but they are probably somewhat like those represented in Figs. 2 and 3, the positive and negative corona rays being quite different. At low pressures there would be many more electrons, $\overset{+}{N}_2$ and $\overset{-}{O}_2$ rays, than of the other types. The positive brushes may consist of regions where ions recombine. These brushes are very ineffective as regards precipitation, fumes and smoke being almost entirely unaffected by them. It seems necessary for precipitation that the suspended particles be subjected directly to the corona rays that are themselves producing secondary ionization. This would lead one to the view that precipitation is not the immediate effect of the electric field on the charge of a smoke particle but that it includes the kinetic energy received by the particle due to collisions with the corona rays.

Best Working Conditions for Electrical Precipitation

1. The best working conditions for electrical precipitation seems to include the action of as uniform and dense a corona as possible upon the gas containing the suspended matter.

2. The effect of temperature is not very great, higher temperatures usually permitting of a larger corona current density.

3. In any gas the conditions should be such that no breakdown between the electrodes should take place. Fluctuations in the ionization of the gases may cause considerable trouble.

4. In actual experiments on a precipitation chamber treating about 1000 cu. ft. of gas per min. it was found that under the most favorable conditions some 5 per cent of the electrical energy could be converted into E_p, as given by equation (**8**). E_c, the amount of energy used up in chemical reactions such as the oxidation of nitrogen, is of the same order of magnitude.

5. The efficiency of the process of electrical precipitation is probably not as great as represented by (**8**) since the corona discharge is not distributed altogether uniformly over the wire.

6. The theory of electrical precipitation can easily be applied to that of a corona wire fixed axially in a cylinder of radius R. Consider a cylindrical shell of the thickness dr at a distance r from the center of the cylinder.

The energy required to remove the particles in this shell (volume $= 2\pi\, r\, dr\, L$) of number $2\pi\, r\, n\, L\, dr$ would be equal to the kinetic energy the particles impart to the cylinder on impact and the energy used up in frictional resistance. One has

E_p for this shell per sec. =

$$\left(\tfrac{1}{2}\, m\, V_r^2 + (R - r)\; 6\, \pi\, \mu\, a\, d\, V_r\right)\; 2\, \pi\, r\, n\, L\, dr,$$

$(R - r)$ being the distance that each particle must traverse in order to reach the outer cylinder. For the whole cylinder this becomes

$$E_p = \int_{r=b}^{r=R} \tfrac{1}{2}\, m\, V_r^2\, dr + 12\, \pi^2\, r\, n\, L\, (R - r)\, \mu\, a\, d\, V_r\, dr \qquad (\mathbf{10})$$

in which b is the radius of the wire electrode. Since the particles have reached a state of equilibrium in each shell (the forces of the electric field and the frictional forces being balanced) V_r is a function of the potential gradient, this latter being a function of r; r then is the only variable in (**10**), so that the expression can be integrated. In this way tables connecting E_p with the amount of corona current, the changes in the gas viscosity, temperature, the potential gradient, etc., can easily be determined.

The best method of attacking equation (**10**) from an experimental point of view is to work with smoke particles of uniform size and density (lycopodium dust for instance), and measure V_r, m, μ, d and n. As the law of Stokes has been proved to hold experimentally for wide ranges in the value of a its use permits us to determine the electrical forces that are in more or less equilibrium with the viscous force of resistance. A determination of V_r for various values of r will serve to indicate how the smoke particles are ionized. Equation (**10**) may be written:

$$E_p = A\int_{r=b}^{r=R} V_r^2\,dr + B\int_{r=b}^{r=R} r\,V_r\,dr - C\int_{r=b}^{r=R} r^2\,V_r\,dr.$$

Since A contains a^3 and this is very small for fine dust, fumes and smoke, we have for the conditions of electrical precipitation:

$$E_p = B\int_{r=b}^{r=R} r\,V_r\,dr - C\int_{r=b}^{r=R} r^2\,V_r\,dr. \qquad \textbf{(11)}$$

The transverse velocity of the ionized smoke particles (V_r) is a function of the potential gradient (E_r) at r and in the direction of r.

$$V_r = f\,(E_r) = f\left(\frac{E}{r\log\frac{R}{b}}\right) \qquad \textbf{(12)}$$

It is thus seen that since E is not a function of r, being the difference of potential between the wire and the cylinder, (**11**) can be integrated. The value of the function f is determined by the size and manner of charging the smoke particles by the corona rays. This is not now well known. We have then for the energy consumed,

$$E_p = B\int_{r=b}^{r=R} r\,dr\,f\left(\frac{E}{r\log\frac{R}{b}}\right) - C\int_{r=b}^{r=R} r^2\,d\,r\,f\left(\frac{E}{r\log\frac{R}{b}}\right) \textbf{(13)}$$

For an example, cigarette smoke was taken. Very dense cigarette smoke may contain a maximum number (n) of 30,000,000 particles per cu. cm. In the actual experimental conditions V_r was assumed uniform and was about 20 cm. per sec. $L = 4$ ft. a was assumed to be 0.01 μ (ranges between 0.1 to 0.001 μ, μ being a thousandth of a mm.), and the coefficient of viscosity 0.000178. The particles were all assumed to traverse a distance of 8 cm. The value of E_p then comes out to be some 20 to 30 watts (per thousand cu. ft. of smoke) and the corona energy consumption 300 watts. This value of E_p is only intended to be a qualitative illustration, but under actual conditions it can be determined with a considerable degree of accuracy.

Conclusions

1. It is shown that the energy (E_p) required for precipitating smoke, fumes and dust can be represented by the formula

$$E_p = K\ V l^2\ l^3$$

where l is the length of the precipitation chamber, V_l is the necessary longitudinal velocity of the particles and K is a constant that can easily be determined in practise.

2. A formula is derived for the corona method of electrical precipitation that will give the efficiency of the process for pipes of different radii, different lengths and for different values of the potential gradient and the transverse velocity. For installing a plant the problem consists in knowing the constants of this formula and then deriving the most suitable type of precipitation chamber.

3. The possible nature of the corona rays is described, the different kinds of ionization that may take place and the way smoke and fume particles may be charged.

4. The distribution of the energy transformations in the corona discharge is outlined and it is shown how it is possible to measure some of these energy terms.

5. It has been shown that approximately 10 per cent of the energy of the corona discharge may be used directly in precipitating smoke. There is no doubt but that this efficiency may be increased.

6. It can be shown that a similar percentage of the energy may be used in the oxidation of the nitrogen by the corona discharge.

Presented at the meeting of the Urbana Section of the American Institute of Electrical Engineers, Urbana, Ill., April 16, 1914.

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MAGNETIC AND OTHER PROPERTIES OF ELECTROLYTIC IRON MELTED IN VACUO

BY TRYGVE D. YENSEN

ABSTRACT OF PAPER

Electrolytic iron of a purity of 99.97 to 99.98 per cent was melted in fused magnesia crucibles in a modified Arsem furnace, forged into rods, machined, and annealed in an electric furnace according to various heat cycles.

.The magnetic properties were obtained by the Burrows double bar method. Determinations were also made of the electrical resistance, chemical composition, and physical properties, including microstructure and critical temperatures as well as tensile tests. A few commercial iron and steel samples were tested for comparison.

The following valuable results were obtained:

1. Pure iron melted in an atmosphere of carbon monoxide under atmospheric pressure will absorb both carbon and oxygen with the result that the iron thus produced is of an inferior magnetic quality.
2. Low carbon iron melted in vacuo will lose 50 to 90 per cent of its original carbon content.
3. The magnetic quality of electrolytic iron melted in vacuo is decidedly superior to any grade of iron thus far produced, the maximum permeability obtained being 19,000 at a flux density of 9500 gausses. The average hysteresis loss obtained is less than 50 per cent of that found in the best grade of commercial transformer steel, due to the fact that the coercive force is very much lower than for silicon steel, although the retentivity is higher.
4. The specific electrical resistance of pure iron melted in vacuo is 9.96 microhms per centimeter cube.
5. Swedish charcoal iron melted in vacuo has a magnetic quality approximating that of electrolytic iron melted in vacuo, chiefly due to the reduction of the carbon content.

The author suggests that the high electrical conductivity and hence large eddy current losses in this material may possibly be greatly reduced by the addition of silicon or aluminum without very materially affecting the magnetic quality.

PREVIOUS to the beginning of the twentieth century Swedish charcoal iron was the best grade of iron that could be found for magnetic purposes. About that time Hadfield[1] produced a number of iron alloys that revolutionized the iron industry so far as magnetic iron was concerned. His 2.5 per cent silicon-alloy and 2.25 per cent aluminum alloy showed

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Manuscript of this paper was received April 20, 1914.

a higher permeability and gave a lower hysteresis loss than the purest Swedish iron. Perhaps even more important was the high electrical resistance of these alloys, reducing the eddy current loss to one-third or less of that of the Swedish iron under identical conditions. At the same time Barrett[2] showed that the increase in electrical resistance due to the addition to pure iron of one per cent of any alloying element is inversely proportional to the atomic weight of that element.

Since the time of the appearance of Hadfield's alloys comparatively little improvement has been made in the magnetic quality of the iron and iron alloys. What has been done has mostly been in the way of modifications of Hadfield's silicon steel. In 1906, however, Professor C. F. Burgess[3] of Wisconsin commenced a series of investigations upon the magnetic and allied properties of electrolytic iron and its alloys with other elements. While the improvement made by Burgess were not revolutionizing, his investigations, I think, have pointed out the direction in which improvements may be expected. In 1910, E. M. Terry[4], also of Wisconsin, investigating the effect of temperature upon the magnetic properties of electrolytic iron as deposited, found that this iron, after annealing at 1100 deg. cent. and slow cooling, has a very high permeability and a low coercive force. On account of its high retentivity, however, the hysteresis loss was found to be higher than for Swedish charcoal iron.

In 1911 the writer commenced an investigation of the magnetic properties of iron in the Electrical Engineering Department of the University of Illinois. Doubly refined electrolytic iron, deposited according to the methods used by Burgess, has formed the basis for the investigation. It was deposited from Swedish charcoal iron, of the following composition:

C	0.163	per cent
Si	0.032	" "
S	0.0002	" "
P	none	
Mn	none	
Fe (by difference)	99.8	" "

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1. Barrett, Brown and Hadfield, *Jour.* Inst. Elec. Engrs., Vol. 31, p. 674, 1902.

2. *Proc.* Royal Society, Vol. 69, p. 480, 1902.

3. See *Electrochem. & Metal Ind.* for 1909 and 1910. A series of articles by Burgess and Aston.

4. *Phys. Rev.*, Vol. 30, p. 133, 1910.

The doubly refined iron contains:

C	0.006	per cent
Si	0.01	" "
S	trace	
Fe (by difference)	99.98	" "

The crucibles used were made from electrically fused magnesia containing about two per cent silica, and these crucibles were placed in graphite crucibles and securely covered. At first a Hoskins resistance furnace was used for the melting of the iron but this was abandoned after a large number of attempts had been made to keep the iron from being contaminated. If the crucibles were left exposed in the furnace the iron was so badly oxidized that it cracked to pieces under the hammer in the attempt to forge it. If buried in crushed carbon the iron absorbed comparatively large quantities of carbon. Burgess used the latter method and found that the iron absorbed from 0.05 to 0.15 per cent carbon, probably by reducing the carbon monoxide

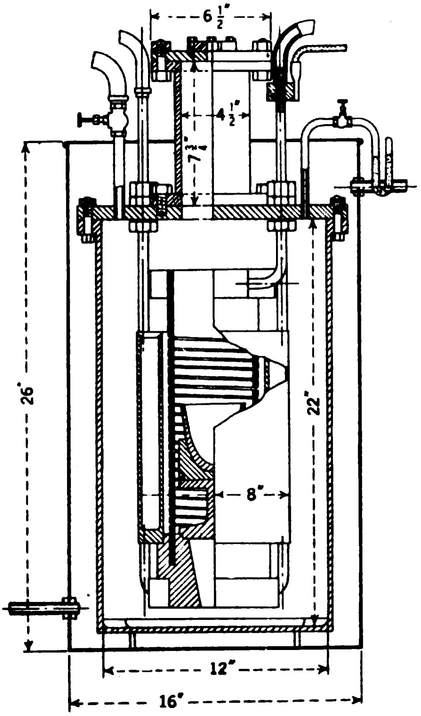

FIG. 1—VACUUM FURNACE

gases surrounding it. The results obtained by the writer agree with those obtained by Burgess, so far as the carbon is concerned, but as will be shown later, carbon alone does not account for the properties of the iron thus produced.

In order to overcome the difficulties above referred to, a vacuum furnace was constructed in the shops of the department. It is modeled after the Arsem type of furnace, and is shown in Fig. 1 and Fig. 2. The inside parts consist entirely of graphite cut from solid graphite electrodes, with the exception of the water-cooled copper tubes, that serve as supports as well as leads. A Geryck pump is capable of maintaining a pressure of 0.5 cm. or less with 500 to 600 grams of molten iron in the furnace. The state of the charge may be observed through a mica window in the top.

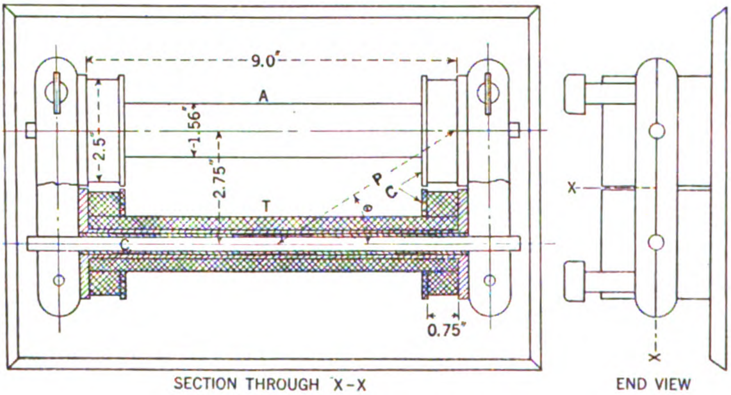

FIG. 3—PERMEAMETER

While the results obtained with this furnace are not as uniform as might be desired, it must be remembered that the tests have necessarily been made upon relatively small samples, that the processes involved in order to obtain the test pieces in the final condition are numerous, and that the magnetic properties of this material are very readily affected by outside influences. The chemical composition of the final iron is quite uniform.

METHOD OF MAGNETIC TESTING

A number of different instruments for the magnetic measurements were tried and discarded. The main defect of most of them was that large and uncertain corrections had to be made to the readings in order to arrive at the correct results. As it was desirable to make a large number of test pieces, Rowland's ring method was impracticable on account of the difficulty of construction, and also because of the difficulty of electrical resistance measurements. An instrument was needed that could measure accurately the magnetic properties of relatively short rods. The one finally decided upon was constructed by the writer in the shops of the department in accordance with the recommendations of the Bureau of Standards.[5] The details of this instrument[6] are shown in Fig. 3 and a diagram of the connections in Fig. 4. Briefly stated, it consists of a double bar and yoke with one main solenoid *T*, and one auxiliary solenoid *A*, separately controlled, and four compensating solenoids, *C*, next to the yokes connected in series. Each of these coils was wound with No. 18 B. & S. gage double-cotton-covered wire in 10 layers of exactly 20 turns per inch (= 7.875 turns per cm.). By means of the three secondary coils, *t*, *a* and *c*, the magnetic flux

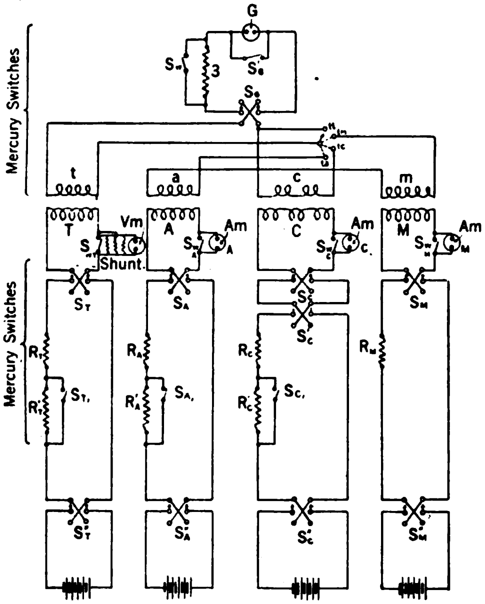

FIG. 4—ELECTRICAL CONNECTIONS FOR PERMEAMETER

can be investigated at different points of the magnetic circuit and equalized by adjusting the currents in the magnetizing coils. With no leakage of flux, the magnetizing force for the rod measured is

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[5] *Bulletin*, Bureau of Standards, Vol. 6, No. 1. Reprint No. 117.

[6] For further information regarding the various apparatus and instruments here described, the reader is referred to Bulletin No. 73 of the Engineering Experiment Station of the University of Illinois.

$$H_T = 0.4\pi\, n_T\, I_T$$

where n_T = number of turns per cm. of main solenoid,
I_T = current in main solenoid in amperes.

This is strictly true if the effects of the ends of the various magnetizing coils are negligible. These end effects have been calculated and the correction to be applied to H_T found to be less than +1 per cent for ordinary iron for all values of H. For the highest permeability iron found in this investigation, however, the correction for low values of H, on account of the high compensating currents required in coils C, has been found to vary from +4 per cent for low values of H to less than +1 per cent for values of $H = 8$ or above. For reasons to be given presently, these corrections have not been made in the results given in this paper.

For the determination of B a ballistic galvanometer of a 15-second period was at first employed. This was calibrated by means of a mutual inductance, consisting of a primary coil, M, 10 cm. in diameter and 90 cm. long, of No. 18 B. & S. double-cotton-covered wire, 20 turns per inch (=7.875 turns per cm.), with a secondary m, of 1260 turns of No. 30 double-silk-covered wire, wound in 10 layers occupying 8 cm. at the center of the primary. The error due to the end effects of this coil is such that if it be assumed that the magnetizing force H_M at the center of the calibration coil M is

$$H_M = 0.4\pi\, n_M\, I_M$$

then the values found for B_t of the rod tested are high by 0.3 per cent.

The ballistic galvanometer served the purpose very well until the electrolytic vacuum iron was ready to be measured in the annealed state. On account of the high permeability and low electrical resistance of this iron, the change of magnetism was found to be too sluggish for accurate determinations with a ballistic galvanometer. This was particularly true for hysteresis determinations. Five or six seconds were sometimes required for the flux to complete the change, so that by the time the galvanometer coil had reached its maximum deflection the flux was still changing. It was, therefore, very evident that the galvanometer had reached its limit of usefulness, even though its period had been doubled.

To overcome this difficulty a Grassot fluxmeter was used for all the final measurements. In this instrument the suspension effect has been practically eliminated, and its deflections are independent of the time required by the flux to complete the change.

All the different connections for operating the permeameter are made through rocking mercury switches operated by means of keys similar to piano keys. In this manner any number of switches may be operated simultaneously, and comparatively little time is occupied in making the adjustments. A view of the operating table is given in Fig. 6.

The magnetization curves are obtained by the method of reversal, by first adjusting the currents in A and C until the flux is equalized at all parts of the magnetic path.

The hysteresis loops are determined in a similar manner, but instead of going from $+H_{max}$ to $-H_{max}$, the change is made by inserting the resistances R'_T, R'_A, and R'_C in the magnetizing circuits by opening the switches S_{T_1}, S_{A_1} and S_{C_1} either alone or simultaneously, with the reversing switches S_T, S_A, and S_C. In this manner the change is always made from H_{max} to the various points on the loop, and the effect of the viscosity of the iron is eliminated.

In Fig. 5 are shown three magnetization curves for the standard rod, No. 3-33 B. One is drawn according to the certificate supplied by the Bureau of Standards for this rod. The other two were obtained by the writer, in one case by using the Grassot fluxmeter and in the other by means of the ballistic galvanometer. There is some doubt as to the case of the discrepancy for low and medium densities between the curve as obtained by the Bureau and that obtained by means of the fluxmeter. On this account the corrections above referred to have not been made, as the writer feels that, if his results be slightly in error, the error is on the safe side.

DETAILS OF THE EXPERIMENTS

The electrolytic iron previous to being placed in the crucible to be melted was crushed into small pieces and thoroughly cleaned with hydrochloric acid, boiling distilled water, and alcohol. It was then transferred to the crucible, covered with a magnesia cover and placed in the vacuum furnace. The furnace was exhausted immediately and heated up, slowly at first, so as to give the absorbed gases time to escape without too much loss of vacuum. With the furnace at a dull red heat the melting would then require about ½ hour with an input of 15 kw. In order to insure homogeneity 12 kw. was left on for another 15 minutes and the furnace then allowed to cool.

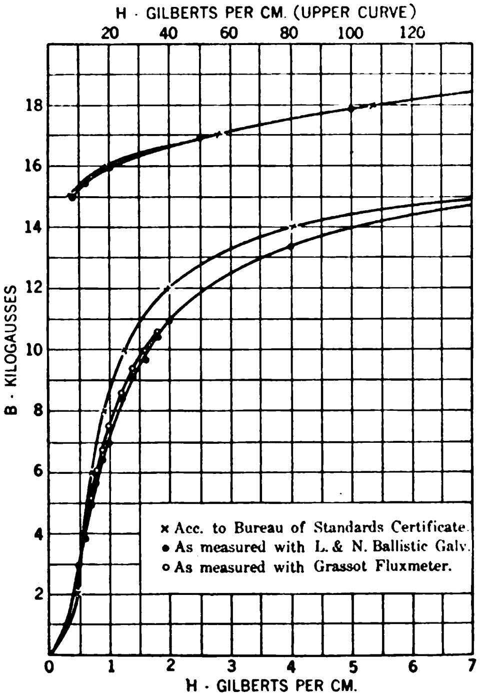
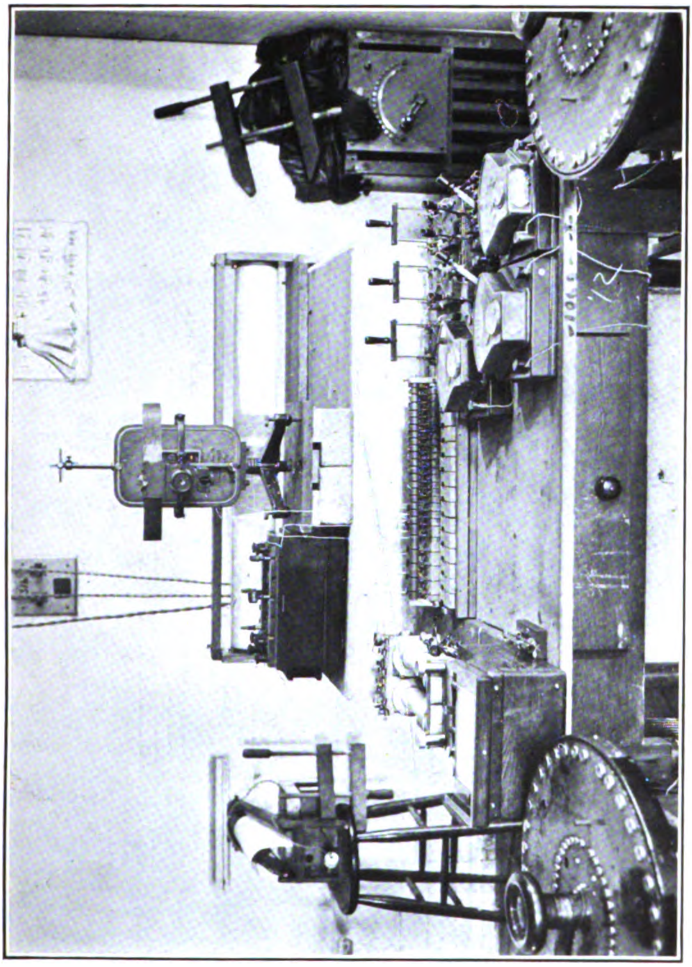


FIG. 5—MAGNETIZATION CURVES FOR STANDARD ROD NO. 3-33B

When removed from the furnace the ingots were as bright as silver and so soft that they could be cut with a knife. They were reheated in a coke forge to ordinary forging temperatures, 1000 to 1100 deg. cent., and forged into rods about ½ in. by 20 in. (1.25 by 50 cm.).

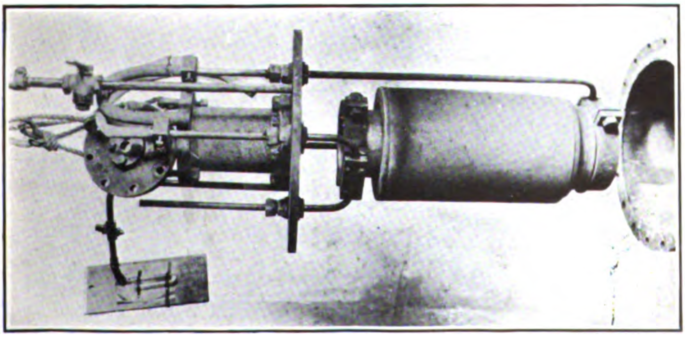
From these rods the following test pieces were prepared:

1. The magnetic test piece, serving also for the electric tests, 0.392 in. (0.996 cm.) in diameter and 14 in. (35.5 cm.) long.
2. Two test pieces for the mechanical tests. These had a



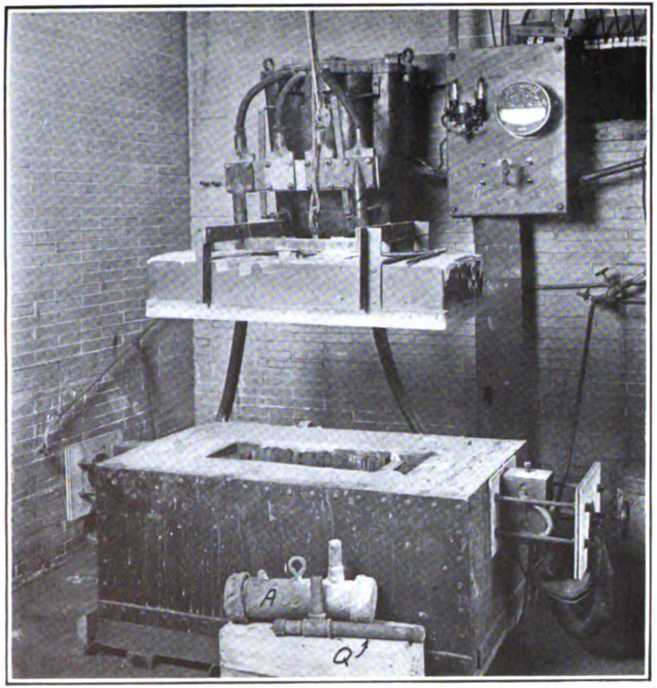
[YENSEN]

FIG. 6—OPERATING TABLE FOR MEASUREMENTS WITH PERMEAMETER



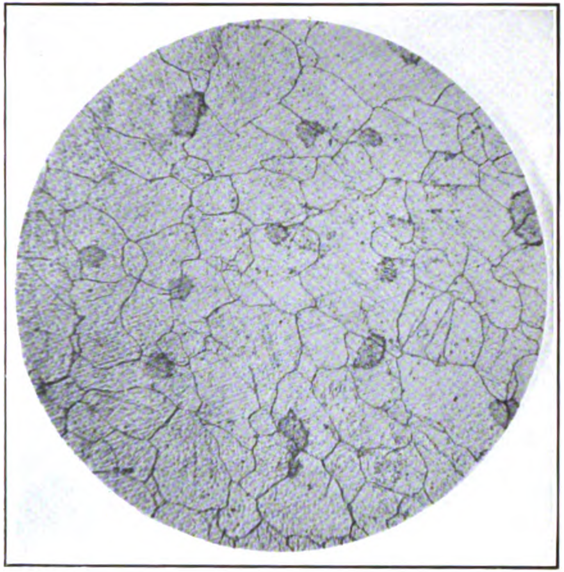
[YENSEN]

FIG. 2—VACUUM FURNACE,
INSIDE VIEW



[YENSEN]

FIG. 7—ANNEALING FURNACE



[YENSEN]

FIG. 13—ROD NO. 3-39A, AS FORGED; ELECTROLYTIC IRON MELTED IN VACUO. MAGNIFIED 60 DIAMETERS

middle section 0.3 in. (0.76 cm.) by 1½ in. (3.8 cm.), with threaded ends, ½ in. by ½ in. (1.25 cm.).

3. One test piece for the study of the microstructure, ½ in. by ½ in. (1.25 cm.).

4. One test piece for the critical temperature determination.

For the chemical analysis the shavings obtained from the preparation of these test pieces were collected, after first removing the outside coating of oxide.

After being tested as forged, the test pieces (1 and 3 above) were sent through different heat treatments. If they were to be annealed they were packed in pulverized magnesia in an iron cylinder, *A*, and placed in the annealing furnace shown in Fig. 7. In order to minimize the formation of oxide the magnesia was moistened with alcohol to drive out the air. After reaching the annealing temperature desired, the cooling was done, in all but the preliminary tests, in accordance with definite cooling curves. The temperature was measured by means of a platinum-platinum +10 per cent rhodium pyrometer, calibrated from time to time.

Quenching was done by placing the test pieces in the cylinder *Q*, Fig. 7, filled with magnesia and moistened with alcohol. When the desired temperature was reached, the cylinder was removed from the furnace, tipped up, and the contents plunged into the quenching bath by means of a sharp blow on the top of the cylinder.

As mentioned above, a small specimen was prepared for the critical temperature determinations of each rod. These determinations were made by placing the specimen in a ½-in. (1.25-cm.) "electroquartz" pyrometer tube, with the hot junction of the pyrometer inserted in the small hole made in one end of the specimen. The tube was partly filled with fused magnesia and placed in a Hoskins muffle furnace with the end at the middle of the furnace. The temperature was gradually raised to about 1000 deg. cent., the current cut off and the furnace allowed to cool naturally, while the time interval for each 10 deg. cent. was obtained by means of two stopwatches. From the data thus obtained three different curves were plotted for each specimen, namely, (1) the temperature-time curve, using temperature as abscissa and time as ordinate; (2) the temperature-rate curve, using temperature as abscissa and the number of deg. cent. fall in temperature per minute as ordinate; (3) the temperature inverse rate curve, using temperature as abscissa and number of seconds per deg. cent. fall in temperature as ordinate. From these curves the critical temperatures can readily be located.

While this method is not as accurate as the differential method by means of three thermocouples, it serves as a check upon the other determinations made in the course of the investigation.

From the chemical analysis of the Swedish charcoal iron and the doubly refined electrolytic iron it is seen that the only measurable impurities in the latter are carbon and silicon. As these are the only impurities that are liable to be affected during the processes described, it seemed superfluous to analyze for anything except carbon and silicon. A few analyses were made for sulphur, but only traces could be found.

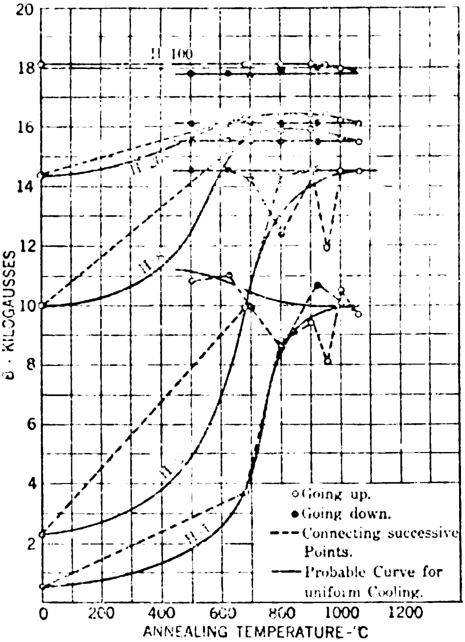


FIG. 8—EFFECT OF ANNEALING TEMPERATURE UPON PERMEABILITY, ROD NO. 3-39

All the rods tested have been analyzed for carbon by direct combustion. On account of the small quantities dealt with, extreme care had to be used in these analyses.

RESULTS

The results of the investigation are embodied in the following tables and figures. In order to ascertain the most favorable annealing temperature, one of the rods, No. 3-39, was annealed at a number of different temperatures ranging from 500 deg. to 1060 deg. cent., in every case followed by a natural cooling of the furnace. The result is shown graphically in Fig. 8.

TABLE I.
SUMMARY OF RESULTS
RODS THOROUGHLY ANNEALED AT 900 DEG. CENT.

Rod No.	Description of iron	Furnace used for melting	Carbon as per chemical analysis, per cent	Max. permeability	Flux density for max. perm.	Hysteresis loss, ergs per cu. cm. per cycle		Coercive force for Bm = 15000	Retentivity for Bm = 15000	Spec. elect. resist. at 20° C. microhms	Crit. temp. Ar_3 deg. cent.
						Bm = 10000	Bm = 15000				
3-38	Electrolytic	Vacuum	0.0104	19000	9500	813	1640	0.295	12100	10.0	905
3-39	"	"	0.0110	16500	8500	880	1860	0.32	12600	9.95	905
3-34	"	"	0.0090	16000	6500	895	1600	0.30	10600	10.2	895
3-49	"	"	0.0120	15400	5000	902	1710	0.31	8100	9.9	
3-31	"	"	0.0120	13100	6200	980	1760	0.32	9100	10.03	885
3-43	"	"	0.0196	12900	5500	1165	2180	0.40	10200	9.85	895
3-48	"	"	0.0080	12600	5500	955	1850	0.29	9300	9.7	
3-36	"	"	0.0150	12250	6000	953	1830	0.33	9000	10.16	875
3-40	"	"	0.0110	12000	9000	1240	2500	0.36	10100	9.7	895
3-47	"	"	0.0080	11900	8000	1190	2120	0.35	9000	10.05	900
3-50	"	"	0.0099	11600	5000	995	1940	0.30	9000	9.7	
3-41	"	"	0.0035	11250	4500	1155	2180	0.40	10000	10.0	895
3-30	"	"	0.0090	11050	5500					9.94	
3-45	"	"	0.0080	10500	9000	1470	2640	0.40	10600	9.87	895
3-37	"	"	0.0450	8050	4500	1255	2000	0.40	9500	10.3	885
Avg.	"	"	0.0125	12950	6550	1060	1990	0.34	9940	9.96	894
Avg. for Iron melted in resist. furnace			0.1000	1965	3930					13.53	
3C01	0.05%C added	Vacuum	0.0130	8600	6000	1405	2300	0.40	10000	10.24	895
3C02	0.10%C added	Vacuum	0.0120	7600	7000	1710	3190	0.50	10700	10.64	895
3C03	0.50%C added	Vacuum	0.1810	4400	5500	1910				12.40	
1-21	Sw. charc. iron remelted in vacuum		0.0080	10350	7000	1290	2640	0.48	11200	10.30	
COMMERCIAL GRADES											
SwI-4	Sw. charc. iron cut from plate.		0.1630	4870	6600	2490	4530	0.95	8000	10.57	
G1&2	Stand. transformer steel*			3850	7000	3320	5910	1.33	9900	11.09	
H1&2	4 per cent silicon steel.*			3400	4300	2260	3030	0.88	5400	51.15	

*Received manufacturer's standard anneal.

Based upon the results obtained with No. 3-39, the 15 rods made from electrolytic vacuum iron were tested after various heat treatments. The final heat treatment received by all of the rods consisted in annealing at about 900 deg. cent. and cooling in 48 hours according to a straight time-temperature curve, connecting 900 deg. and 200 deg. cent. To give the details of the results obtained after the various treatments, would be beyond the scope of this paper, and only the final results can be included. In Table I the rods have been arranged according to the maximum permeability obtained for each rod, and this shows the hysteresis loss and other magnetic data, as well as the carbon content of the rods and their electrical resistance. The last column gives the critical temperature Ar_3 whenever measured. Fig. 9 shows the magnetization curves for the average and best electrolytic vacuum iron, and Fig. 10 shows the hysteresis loops and permeability curve for the best rod, No. 3-38.

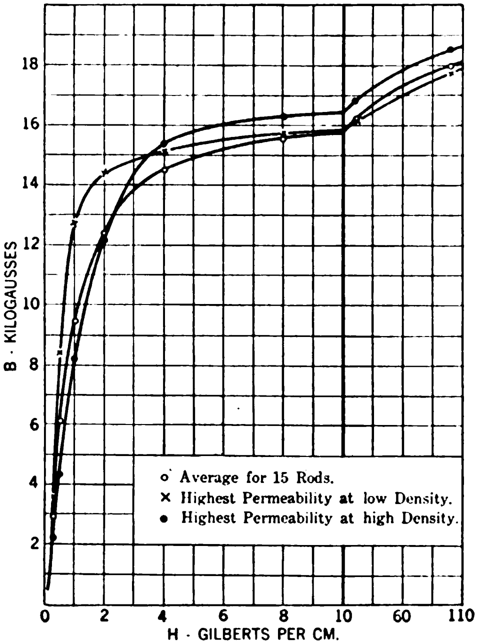


FIG. 9—AVERAGE AND HIGHEST MAGNETIZATION CURVES FOR ELECTROLYTIC IRON MELTED IN VACUO

For the sake of comparison a number of other rods have been tested and the results included in this paper. Sw.I-4 is a rod cut from a plate of Swedish charcoal iron, and No. 1-21 is made from iron cut from the same plate as Sw.I-4 and directly next to it, but remelted in vacuo. No. 3C01, No. 3C02 and No. 3C03 are three rods made from electrolytic iron with additions of 0.05, 0.10 and 0.50 per cent carbon, respectively, and melted in vacuo. G-1 and G-2 are two rods made from such commercial bars as are generally rolled into sheets known as "standard electrical sheets." H-1 and H-2 are rods made from bars containing about 4 per cent silicon. These two sets were supplied by the manufacturers and have received their standard anneal. They are supposed to represent good commercial steel used for electrical machinery. Table I also includes some information with regard to the properties of the electrolytic iron as melted in the resistance furnace. Figs. 11 and 12 show the magnetization curves for all the rods, compared with the average for the electrolytic iron melted in vacuo, all after having received the final heat treatment. The results of the mechanical tests are shown in Table II. A few of the photomicrographs are exhibited in

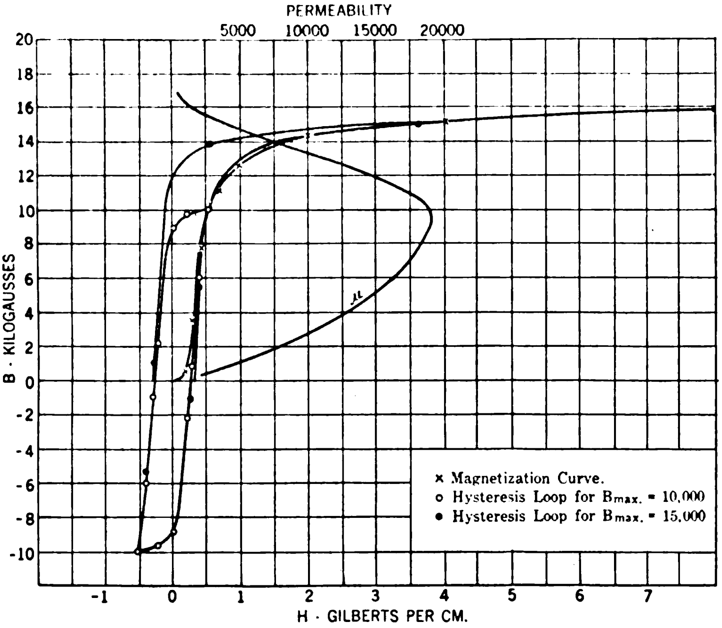


Fig. 10—Hysteresis Loops and Permeability Curve for Rod No. 3-38, Annealed at 900 deg. cent., Cooled in 48 Hours

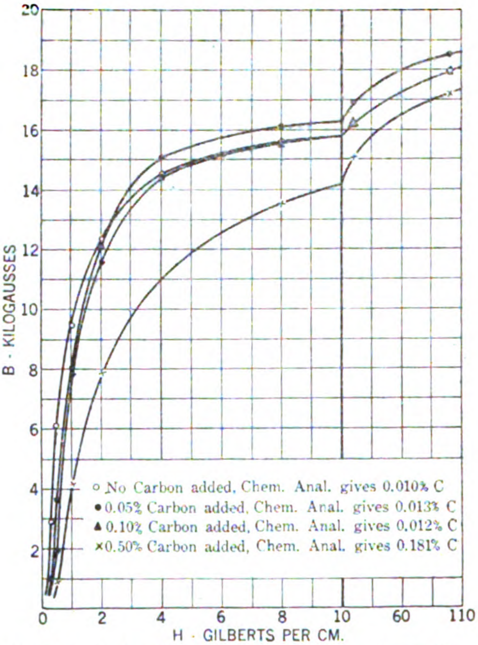


FIG. 11—MAGNETIZATION CURVES FOR THE IRON-CARBON ALLOYS, MELTED IN VACUO

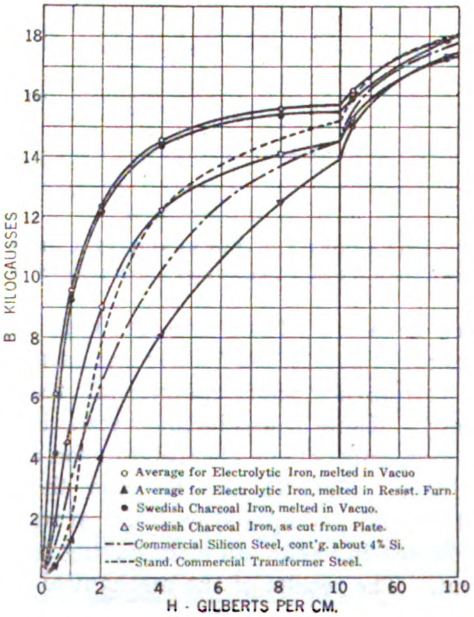


FIG. 12—COMPARISON OF MAGNETIZATION CURVES FOR DIFFERENT GRADES OF IRON

TABLE II.

SUMMARY OF RESULTS OF MECHANICAL TESTS

Spec. No.	Carbon content %	A					B					C					D					Remarks
		As forged					Annealed from 900° to 200° C. in 12 hr. accd. to straight line.					Annealed from 900° to 200°C. in 24hr.acc'd.to log. curve exc. as noted					Quenched in brine from 1000°C. except as noted					
		Stress at yield point lb./sq. in.	Ultimate strength lb./sq. in.	Elong. % 1*	Elong. % 2†	Red'ct of area %	Stress at yield point lb./sq. in.	Ultimate strength lb./sq. in.	Elong. % 1*	Elong. % 2†	Red'ct of area %	Stress at yield point lb./sq. in.	Ultimate strength lb./sq. in.	Elong. % 1*	Elong. % 2†	Red'ct of area %	Stress at yield point lb./sq. in.	Ultimate strength lb./sq. in.	Elong. % 1*	Elong. % 2†	Red'ct of area %	
3-30	0.0090	36 600	44,800		41	87.7																
3-31	0.0120	69,100	70,500		20	82.8	20,700	35,500	30	60	89.5											
3-33		64,000	68,000		22	81.5												40,500	24	53	84.5	
3-34	0.0090												34,300		47	61.1		55,500	14	32	83.1	
3-35												14,400	34,500		54	87.3		44,900	22	44	86.0	
3-36	0.0150											20,100	37,500		52	77.0						
3-37	0.0450																41,250	64,600	15	37	73.7	
3-38	0.0104												35,150		56	85.5	37,400	45,500	17	42	86.1	
3-39	0.0110	35,800	44,700		39	80.4						16,400	36,100		61	80.9						Column C annealed in 48 hr. according to straight line.
3-40	0.0110	39,600	43,500		38	82.3		41,600		42	85.7											
3-41	0.0095	62,200	65,500		26	83.8		40,200	18	53	85.1											
3-43	0.0096						18,750	35,800	31	59	84.5											
3-45	0.0080	51,400	55,500		32	85.8	15,000	39,400	27	40	88											
3-47	0.0080						17,400	36,100	31	57	91.3						30,200	40,000	20	47	80.8	
																	15,500	35,400	27	45	36.6	Quenched in liq. air.
3-48	0.0080	45,600	51,800	12	36	86.4						15,300	35,800	23	42	73.2						Column C annealed 900° to 200° C. in 24hr.acc'd.to straight ne.
3-49	0.0120	41,400	48,700	12	44	76.2						11,100	34,900	23	32	75.7						
3-50	0.0099	38,200		12.5	35							19,300	35,800	28	45	86.5						
Avg.	0.0125	48,390	54,800	12.2	33.3	83.0	17,960	38,100	27.4	51.8	87.4	16,100	35,500	24.7	48.6	78.4	36,280	50.170	18.6	42.5	82.4	
3C01	0.0130						21,000	51,100	27	41	72.5						33,200	53,000	20	65	86.2	%carbon added = 0.05
3C02	0.0120						19,400	38,900	29	60	73.5						67,700	76,900	7	25	79.7	" " " = 0.10
3C03	0.1810						22,100	51,000	24	50	64.5											" " " = 0.5
SwI-4	0.1630		40,000		36	57.0																As cut from plate.

*Elongation before specimen has commenced to "neck." † Ultimate elongation.

Figs. 13-34, including most of those obtained for rod No. 3-39, as this rod received more heat treatments than any other rod. This series for No. 3-39 may be studied to advantage in connection with Fig. 8. Figs. 30 to 32 show the effect upon the microstructure of adding carbon to the iron, and Figs. 33 and 34 show the difference between Swedish charcoal iron before and after being remelted in vacuo. The structure of the electrolytic iron melted in the resistance furnace is shown in Fig. 35. Finally, Fig. 36 is a sample cooling curve for the critical temperature determinations.

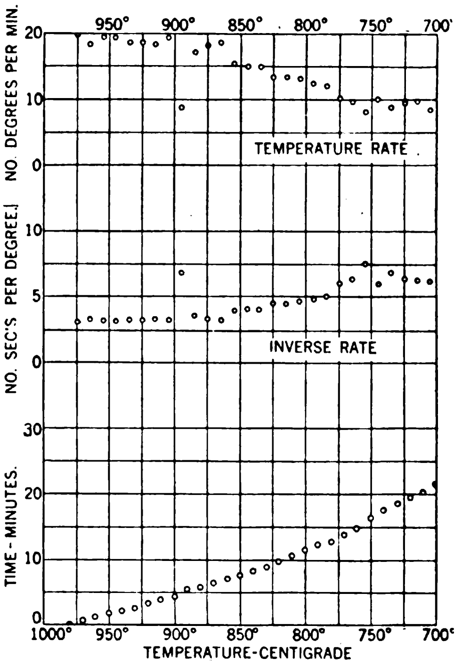
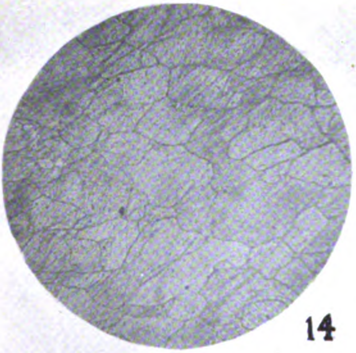


Fig. 36—Cooling Curves for Rod No. 3-43

Discussion of Results

The results obtained may perhaps best be discussed by considering first the equilibrium diagram for iron-carbon alloys. Fig. 37 shows this diagram as represented by Rozenhain.

This diagram should probably be modified somewhat in view of the recent researches upon the critical temperatures for pure iron. It has been shown, for instance, by Burgess and Crowe,



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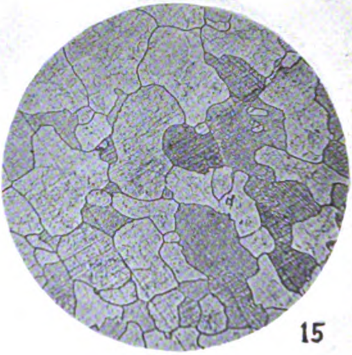

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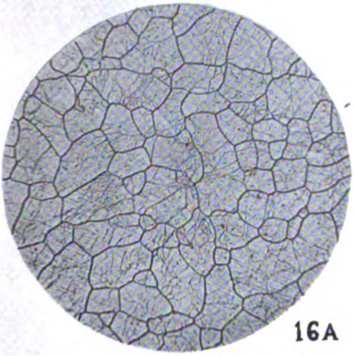
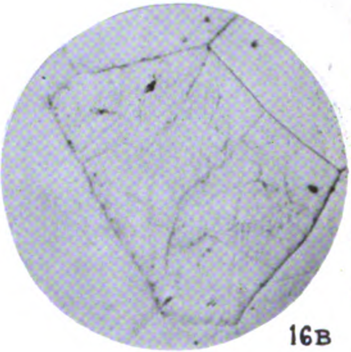
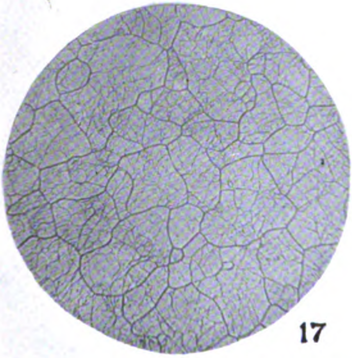


16A



16B



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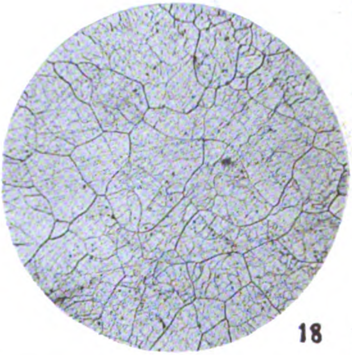


18

[YENSEN]

ELECTROLYTIC IRON MELTED IN VACUO

FIG. 14—No. 3-39B; annealed at 680 deg. cent. going up. 40 diam.

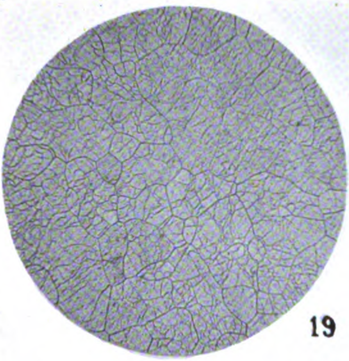
FIG. 15—No. 3-39D and E; annealed at 900 and 950 deg. cent. going up. 40 diam.

FIG. 16A—No. 3-39F; annealed at 1000 deg. cent. going up. 40 diam.

FIG. 16B—Same sample as in FIG. 16A, magnified 240 diam.

FIG. 17—No. 3-39G; annealed at 1060 deg. cent. going up. 40 diam.

FIG. 18—No. 3-39J; annealed at 800 deg. cent. going down. 40 diam.



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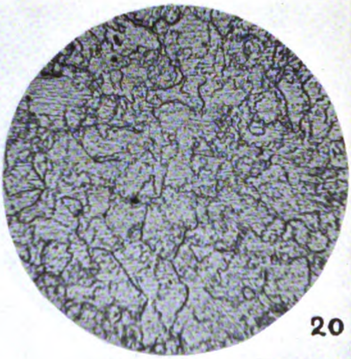

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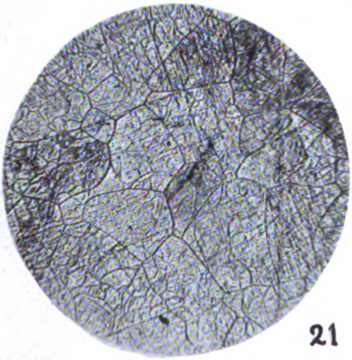

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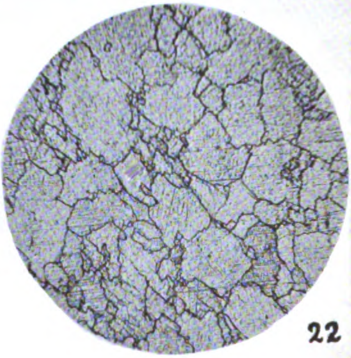

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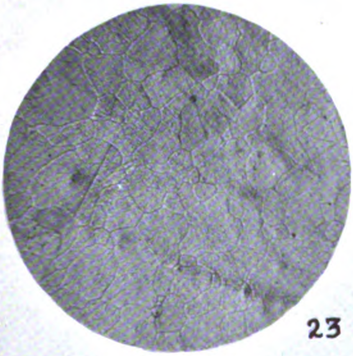

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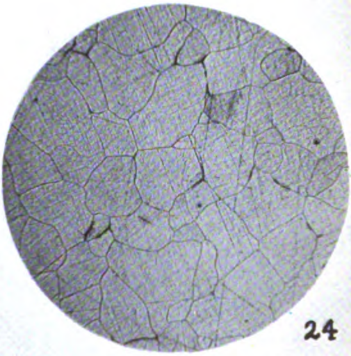
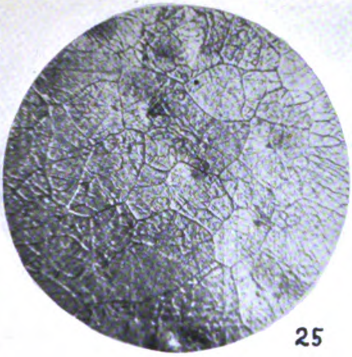


24

[YENSEN]

ELECTROLYTIC IRON MELTED IN VACUO

FIG. 19—No. 3-39L; annealed at 616 deg. cent. going down. 40 diam.
FIG. 20—No. 3-39O; quenched from 1000 deg. cent. in brine. 40 diam.
FIG. 21—No. 3-39S; annealed at 900 deg. cent., cooled in 48 hours. 40 diam.
FIG. 22—No. 3-31A; as forged. 40 diam.
FIG. 23—No. 3-31K; annealed at 900 deg. cent., cooled in 48 hours. 40 diam.
FIG. 24—No. 3-36C; annealed at 900 deg. cent., cooled in 24 hours. 40 diam.



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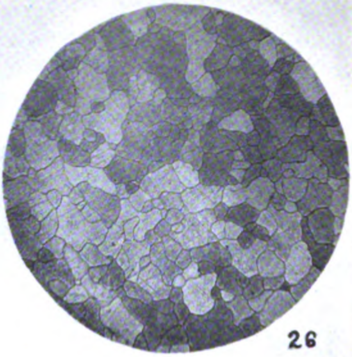

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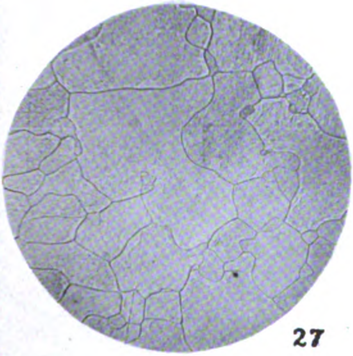

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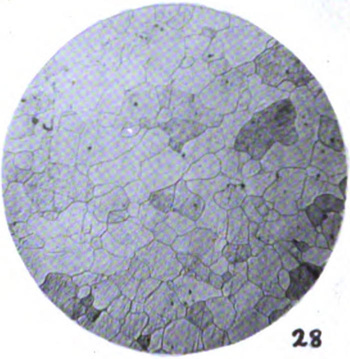

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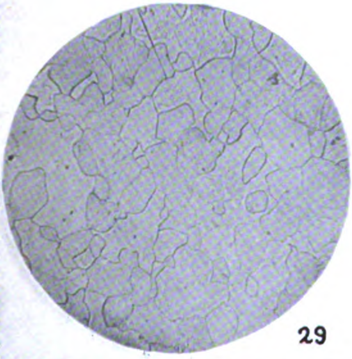

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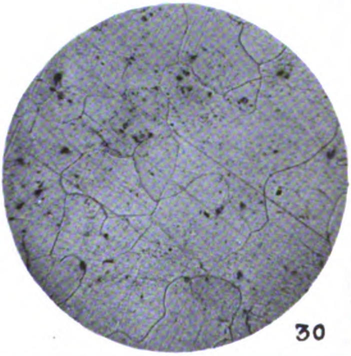

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[YENSEN]

FIG. 25—No. 3-38D, electrolytic iron melted in vacuo; annealed at 900 deg. cent., cooled in 48 hours. 40 diam.

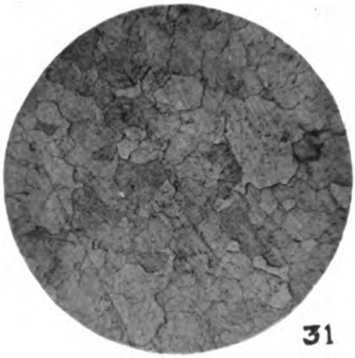
FIG. 26—No. 3-41B, electrolytic iron melted in vacuo; annealed at 900 deg. cent., cooled in 12 hours. 40 diam.

FIG. 27—No. 3-43B, electrolytic iron melted in vacuo; annealed at 900 deg. cent., cooled in 12 hours. 40 diam.

FIG. 28—No. 3-45B, electrolytic iron melted in vacuo; annealed at 900 deg. cent., cooled in 12 hours. 40 diam.

FIG. 29—No. 3-47B, electrolytic iron melted in vacuo; annealed at 900 deg. cent., cooled in 12 hours. 40 diam.

FIG. 30—No. 3C01D, electrolytic iron with 0.05 per cent carbon added, melted in vacuo; annealed at 900 deg. cent., cooled in 48 hrs. Analysis shows 0.013% carbon. 40 diam.



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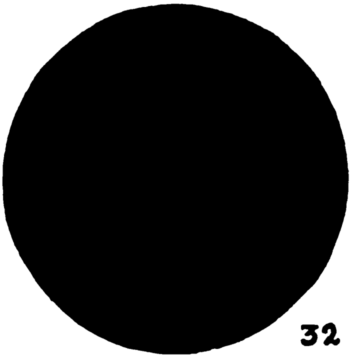

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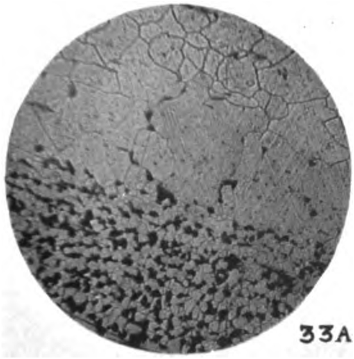
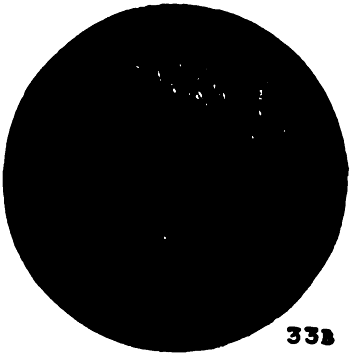
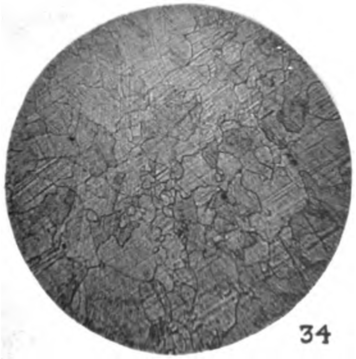


33A



33B



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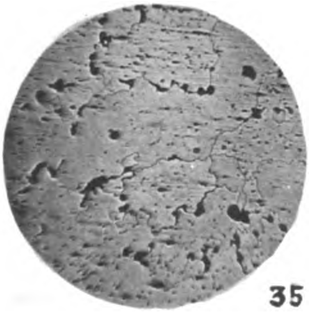

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[YENSEN]

Fig. 31—No. 3C02D, electrolytic iron with 0.10 per cent carbon added, melted in vacuo; annealed at 900 deg. cent., cooled in 48 hours. Analysis shows 0.012 per cent carbon. 40 diam.

Fig. 32—No. 3C03D, electrolytic iron with 0.5 per cent carbon added, melted in vacuo; annealed at 900 deg. cent. Analysis shows 0.181 per cent carbon. 40 diam.

Fig. 33A—No. Sw. I-4B, Swedish charcoal iron cut from plate; annealed at 900 deg. cent. 40 diam.

Fig. 33B—Same sample as in Fig. 33A, magnified 240 diam.

Fig. 34—No. 1-21A, Swedish charcoal iron remelted in vacuo; as forged. 40 diam.

Fig. 35—No. 3-13C, electrolytic iron melted in resistance furnace under atmospheric pressure; annealed at 900 deg. cent. 40 diam.

in a bulletin just issued by the Bureau of Standards, that the point *F*, usually called Ar_2, for pure iron is 768 deg cent. Furthermore, it has been shown conclusively that the temperature at which pure iron changes from a ferromagnetic to a paramagnetic substance or vice versa, is 785 deg. cent., thus showing that these two transformation points do not coincide.

Only that part of the diagram lying to the left of *I* will be considered here. From this diagram it is seen that after the iron has passed from the liquid state it exists in the form of a solid solution of iron and carbon, called austenite. When this solution cools it eventually reaches the line *E G I*, where ferrite crystals begin to be precipitated. Upon further cooling the solution, now enriched in carbon, passes downwards towards the right, following *E G I*, more and more ferrite being precipitated. Finally, upon reaching the point *I*, the part of the solution still remaining, containing now 0.9 per cent carbon, is decomposed into cementite (Fe_3C) and ferrite, and the resulting mixture is called pearlite. At this temperature the iron consequently consists of pure ferrite crystals with the spaces between the crystals filled up with a mixture of ferrite and cementite. One generally-accepted theory states that iron has three different allotropic modifications: Alpha, Beta and Gamma. Gamma iron is stable above the line *E G I*, Beta iron between *E G* and *G F*, and Alpha iron below *G F*. It has been shown that iron in the

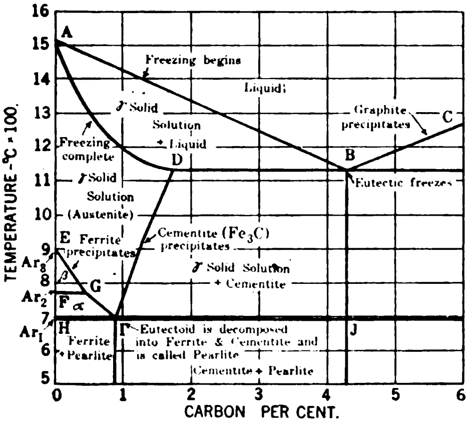

FIG. 37—EQUILIBRIUM DIAGRAM FOR IRON-CARBON ALLOYS, ACCORDING TO ROZENHAIN

Beta and Gamma modifications is weakly paramagnetic, while Alpha iron is ferromagnetic. Under certain conditions Beta and Gamma iron may exist to some extent below the boundaries just stated. It is supposed, for instance, that if iron be cooled rapidly from a high temperature, Gamma and Beta iron may not have sufficient time to change into Alpha iron. If, however, such iron be reheated to above the line *E G I* and slowly cooled, the iron may ultimately all be obtained in the ferromagnetic Alpha modification. This theory is confirmed by the results obtained by Hadfield and Hopkinson, who found that the " specific magnetism " of iron-carbon alloys is decreased to a large but uncertain extent by quenching from a high temperature. Certain elements, carbon and manganese for example, when added to the iron assist in retaining the iron in the Gamma form. Thus Hadfield obtained an iron-manganese alloy that is practically non-magnetic at ordinary temperatures.

Another factor that may influence the magnetic properties of iron is mechanical strain, either due to outside influence or due to rapid cooling. It is not definitely known which is the more important, removing mechanical strain, or changing all the iron into Alpha iron. It is certain that both are important and that both may be accomplished by proper annealing. It is well known that if, subsequent to annealing, the iron be mechanically strained, its magnetic quality is depreciated. This point was confirmed by the writer while measuring a rod that had been slightly bent during the annealing process. Its permeability seemed, compared with previous measurements, to be unusually low. It was noticed that in clamping it in the permeameter it had been strained to some extent. It was then adjusted so as to lessen the strain as far as possible, and the permeability was found to have increased materially. This fact helped to explain some rather puzzling results previously obtained in the course of the investigation. It also showed that, if the iron has not been strained beyond a certain point, the effect of the strain is only temporary.

With the above explanations and facts in mind, the results given in the previous part of the paper will now be considered.

It is at once apparent from Table I that the melting of electrolytic iron, or low carbon iron in general, in an atmosphere of carbon monoxide gases, gives the iron a chance to absorb carbon, the amount absorbed varying from 0.05 to 0.15 per cent. This result is in agreement with the experiments of Burgess and Aston referred to in the introduction. It is furthermore seen that carbon is not the only factor that affects the magnetic properties of iron. Swedish charcoal iron, Sw.I-4, with a carbon content of 0.163 per cent, and 3C03, an electrolyitc iron-carbon alloy melted in vacuo, with a carbon content of 0.181 per cent, both have a decidedly higher permeability than the electrolytic iron melted in the resistance furnace, although the latter has an average carbon content of only 0.10 per cent. Again, the electrical resistance of the resistance furnace iron is 13.52 microhms while that of Sw.I-4 and 3C03 is 10.57 and 12.40 respectively. The carbon content of 0.1 per cent does not by itself account for a resistance of 13.52 microhms. According to Barrett this resistance corresponds to a carbon content of 0.6 per cent. As carbon is probably absorbed from CO according to the reversible reaction

$$\mathrm{Fe} + \mathrm{CO} \rightleftarrows \mathrm{FeO} + \mathrm{C}$$

it seems natural to assume that not only carbon but also FeO is absorbed by the iron. In that case the result would be an alloy of ferrite, cementite (Fe_3C) and iron oxide (Fe O). For a carbon content of 0.1 per cent the alloy would contain 1.5 per cent cementite, and 0.59 per cent FeO. While cementite is slightly ferromagnetic, as shown by Hadfield and Hopkinson, FeO is paramagnetic, and a very poor conductor of electricity. With these two substances interspersed among the ferrite crystals, the low permeability and high resistance can be satisfactorily explained. From a further study of Table I it is seen that the Swedish charcoal iron has lost nearly all of its carbon by being melted in vacuo, the carbon content in the final iron being only 0.008 per cent. At the same time, as would be expected, its electrical resistance has been slightly lowered and its magnetic permeability considerably increased. Similarly, the three iron-carbon alloys melted in vacuo, 3C01, 3C02 and 3C03, have lost the larger part of the carbon added to them. While the additions amounted to 0.05, 0.10 and 0.50 per cent respectively, the chemical analysis of the final rods shows a carbon content of 0.013, 0.012 and 0.181 per cent. If to the former figures be added the carbon content of the electrolytic iron as deposited, namely 0.006 per cent, the loss of carbon is found to be 76.8, 80.5 and 64.4 per cent respectively. The corresponding loss for the Swedish iron was 95 per cent. The Bureau of Standards has demonstrated that such a loss occurs by melting electrolytic iron in vacuo, the loss found being in one case 67 per cent, in another case 87.5 per cent. In the present case the electrolytic iron melted in vacuo not only did not lose any carbon, but actually gained a slight amount. In order to explain this apparent discrepancy it should be mentioned that the pressure used by the Bureau of Standards investigators in their vacuum furnace was 0.01 mm. of mercury, while the pressure used by the writer was from 2 to 5 mm. Based upon the facts above enumerated, the following explanation is now offered. Any oxygen left in the furnace combines with the carbon of the heating element and forms carbon monoxide (CO). This gas, as already stated in connection with the results obtained with the resistance furnace, reacts with the iron according to the reversible equation

$$Fe + CO \rightleftarrows FeO + C$$

until equilibrium is established. If now the pressure in the furnace be lowered the reaction will take place from right to left; that is, any FeO that may be present will be reduced by the carbon in the iron, with the result that the carbon content will be reduced until equilibrium is restored. Conversely, with an increase of pressure due to an admission of oxygen, the reaction will take place from left to right, and the carbon content, as well as the FeO, of the iron will be increased. Upon this hypothesis the difference between the carbon content obtained by the Bureau of Standards and that obtained by the writer is immediately explained.

The changes in the structure of the Swedish iron are very well illustrated by the photomicrographs shown in Figs. 33A and 33B and Fig. 34. Fig. 33A shows the non-homogeneous Swedish iron as rolled. The dark spots are probably partly slag and partly pearlite, shown to a higher magnification in Fig. 33B. Fig. 34 shows the iron after being melted in vacuo, being perfectly homogeneous and without any sign of pearlite. Figs. 30 to 32 show the structure for the iron-carbon alloys 3C01, 3C02 and 3C03, verifying in general the chemical analysis as to carbon content. By referring to Fig. 11 and Table I, it is seen that the electrical resistance and magnetic permeability for these iron-carbon alloys are not strictly in accordance with the chemical analysis. From the latter, 3C01 and 3C02 are approximately alike, while the electrical and magnetic tests indicate that 3C02 should have a higher carbon content than 3C01. Why this discrepancy should exist is difficult to explain, as the analysis for 3C02 was repeated four times, giving results that agreed quite closely.

The effect of annealing at different temperatures is shown graphically in Fig. 8. From this figure it is seen that the permeability increases quite uniformly as the annealing temperature is raised, at first slowly, and then very rapidly as the annealing temperatures are raised from 700 to 800 deg. cent. Above 900 deg. cent. some uncertainty appears. The permeability is decreased for 950 deg. and again increased for 1000 deg. cent. Whether this result is due to mechanical strain in clamping the rod in the permeameter or whether it is due to different rates of cooling or to some other cause, the writer is not prepared to say. From the experience previously related it seems most probable that the drop for 950 deg. is due to mechanical straining, as it occurs for low values of H only. The experiments of Terry show that 1100 deg. cent. is the most favorable annealing temperature for pure iron. While the results shown in Fig. 8 are not conclusive in themselves, they help to confirm the results obtained by Terry. Another interesting point is shown in Fig. 8. For values of $H = 8$, or above, the permeability is decreased by annealing at temperatures above 900 deg. cent., and does not return to the higher value by further annealing at lower temperatures. Furthermore, upon annealing successively at decreasingly lower temperatures, the permeability is increased for low values of H. Such a process is, of course, equivalent to annealing at the highest temperature and cooling at a slower rate than was used for each of the successive annealings. This assumption was verified by annealing at 900 deg. cent. and cooling, first in 24 hours according to a logarithmic time-temperature curve, and finally in 48 hours according to a straight line connecting 900 and 200 deg. cent. These treatments increased the permeability considerably for low values of H, but did not alter it for high values of H. Quenching from 1000 deg. cent. in iced brine produced a decidedly magnetic hardening, but this hardening was again removed by reheating to 900 deg. cent. and slow cooling.

The results obtained with rod No. 3-39 are confirmed by those obtained with the three groups of rods made from electrolytic iron melted in vacuo. Thus, the rods of group 2, including Nos. 3-34, 3-36, 3-37 and 3-38, that were reheated to forging temperature, between 1000 and 1100 deg. cent., give a decidedly lower permeability for high values of H than rods that have not been heated above 900 deg. cent. The same is shown by the results obtained for the rods of group 4, including Nos. 3-48, 3-49 and 3-50, after these rods had been annealed at 1080 deg. cent. Whether annealing at temperatures above 900 deg. cent. improves the permeability for low values of *H* has not been definitely demonstrated by this investigation. As was mentioned above, Terry has shown that 1100 deg. cent. is the most favorable annealing temperature for electrolytic iron as deposited, as this gave a lower hysteresis loss than annealing at lower temperatures. To be sure, the rods belonging to group 2, as well as rod No. 3-39, that some time during the process were heated above 1000 deg. cent., include the best rods magnetically of the entire series.[7] But the rods of group 4 were not improved materially by annealing at 1080 deg. cent. after having previously been annealed at 900 deg. cent.

The average magnetization curve for electrolytic iron melted in vacuo, as shown in Figs. 11 and 12, is based upon the results obtained after the final heat treatment, whether this gave the best results for each particular rod or not. This average also includes the results for rod No. 3-37, that perhaps should have been thrown out. The average curve is, therefore, somewhat lower than might be expected for 15 rods treated under more favorable conditions. However, it serves to indicate the place occupied by electrolytic vacuum iron, in relation to other grades of iron.

While the curve for the electrolytic vacuum iron is the highest of those represented in Fig. 12, the curve for the Swedish charcoal iron remelted in vacuo is a close second, and these two are far above the curves for commercial iron used at present for magnetic purposes. The maximum permeability for the average magnetization curve, as shown by Table I, is 12,950, occurring at a flux density of 6550 gausses. The maximum obtained, however, is 19,000 for rod No. 3-38, at a flux density of 9500 gausses.

Terry gives 11,000 as the maximum permeability obtained for electrolytic iron as deposited, but it is not perfectly clear whether this permeability occurred at ordinary temperatures or in the neighborhood of 760 deg. cent., as he compares this maximum value obtained with that obtained by Morris (15,000) and that obtained by Wells (17,000), both of which occurred at very low flux densities and near the critical temperature, 785 deg. cent. However, it is believed that Terry's maximum occurred at room temperature after annealing at 1100 deg. cent.

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[7] Rod No. 3-37 has an exceptionally low permeability but this rod had probably had an accident sometime, as the chemical analysis shows that it contains 0.045 per cent carbon.

While high permeability is of interest for certain purposes, the characteristics of iron that are of special interest to the manufacturer and user of electrical machinery are hysteresis and eddy current losses, the latter depending largely upon the electrical resistance of the iron.

From Table I the hysteresis loss for $B_{max} = 10,000$ is seen to be less than one-half as high for the average electrolytic vacuum iron as it is for the commercial silicon steel, while for $B_{max} = 15,000$, the corresponding figure is about two-thirds. The reason why the hysteresis loss for the vacuum iron is not even still lower, compared with commercial iron, is readily seen by looking at the figures for retentivity. (See also Fig. 10). While the retentivity for $B_{max} = 15,000$ is 9940 for the average electrolytic vacuum iron, it is only 5400 for silicon steel. The hysteresis loss for Hadfield's best magnetic steels, the $2\frac{1}{2}$ per cent silicon alloy and the $2\frac{1}{4}$ per cent aluminum alloy, as reported by Barrett, Brown and Hadfield, for $B_{max} = 9000$ is 1550 and 1440 ergs, respectively, per cu. cm. per cycle. Comparing these results, it is seen that in spite of the high retentivity, the hysteresis loss for the electrolytic vacuum iron is much lower than for any material thus far produced, of which the literature gives information. This is due to the low coercive force, namely, 0.34 gilbert per cm. this being the average value for the 15 rods.

The electrical resistance for the average vacuum iron is 9.96 microhms per cm. cube. The resistance for the standard transformer steel is 11.09 microhms, while that for the silicon steel is 51.15 microhms. Thus the eddy current losses per unit volume, for the same thickness of sheet and for the same maximum flux density, would be much in favor of the silicon steel. However, it is definitely known that the resistance of the latter can be raised by the addition of silicon or aluminum. What the effect of such additions upon the magnetic quality of the iron will be, remains to be seen, but judging from the effect they have upon commercial grades of iron, it seems probable that it will not be harmful.

While the photomicrographs are of interest primarily as showing the structure of electrolytic vacuum iron in general, and in what respects it differs from other grades of iron, certain conclusions as to the relation between the microstructure and the magnetic quality of the iron may be drawn. Considering the series for rod No. 3-39, it appears that there is no general growth in the size of crystals. Annealing above 900 deg. cent., with subsequent slow cooling, breaks the crystals up into smaller parts. Quenching from 1000 deg. cent., this fine structure again gives way for larger crystals with indefinite boundaries, but the fine structure reappears upon subsequent annealing and slow cooling. The structure that seems to give the best magnetic quality is that shown in Figs. 19 and 21 for rod No. 3-39. This same structure is obtained for the best rod of the series, No. 3-38, as shown in Fig. 25, and for No. 3-31, in Fig. 23. The results of the critical temperature determinations show that the point Ar_3 (see Fig. 37) for the average electrolytic vacuum iron is 894 deg. cent., agreeing with the value found by the Bureau of Standards for pure iron.

Table II shows that magnetic and mechanical hardness go together, and serves to confirm further the results obtained by previous writers. It emphasizes the extreme mechanical softness of the electrolytic iron melted in vacuo, particularly after annealing at 900 deg. cent. In comparing Nos. 3C01, 3C02 and 3C03 with the rest of the rods, it should be remembered that the actual carbon content of these rods is 0.013, 0.012 and 0.181 per cent, respectively.

SUMMARY AND CONCLUSION

The results recorded in the previous pages may be summarized as follows:

1. Pure iron melted in an atmosphere of carbon monoxide, under atmospheric pressure, will absorb both carbon and oxygen, with the result that the iron thus produced is of an inferior magnetic quality.

2. Low carbon iron melted in vacuo will lose 50 to 90 per cent of its original carbon content.

3. The magnetic quality of electrolytic iron melted in vacuo is decidedly superior to any grade of iron thus far produced, the maximum permeability obtained being 19,000 at a flux density of 9500 gausses. The average hysteresis loss obtained is less than 50 per cent of that found in the best grades of commercial transformer iron.

4. The specific electrical resistance of pure iron melted in vacuo is 9.96 microhms.

5. Swedish charcoal iron melted in vacuo has a magnetic

quality approximating that of electrolytic iron melted in vacuo, chiefly due to the reduction of the carbon content.

From these facts it appears that a superior quality of iron for magnetic purposes may be obtained by melting electrolytic iron in vacuo. While the electrical resistance of the iron thus obtained is very low, this defect may be remedied by the addition of such alloying elements as silicon or aluminum, elements that are known to increase the electrical resistance very materially without affecting the magnetic quality to any large extent. Experiments are now under way for determining the effect of such alloying elements, and the results will be published at some later date.

Whether iron melted in vacuo will ever become a commercial product depends, of course, upon whether any apparatus can be devised for producing such iron on a commercial scale at a cost that will not be prohibitive.

In conclusion, the writer wishes to acknowledge his indebtedness to a large number of persons connected with various departments of the University of Illinois, who have rendered valuable assistance in carrying on this investigation.

A number of large manufacturing companies have also shown their willingness to cooperate in the work, by going to great trouble and expense in preparing rods from commercial grades of iron.

To be presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 17, 1915, under the auspices of the High-Tension Transmission Committee.

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EFFECT OF MOISTURE IN THE EARTH ON TEMPERATURE OF UNDERGROUND CABLES

BY L. E. IMLAY

Abstract of Paper

The author describes a permanent installation which was made for supplying moisture to the earth in the neighborhood of underground cables with the object of reducing their temperature. The approximate temperature of the cables is found by taking with a resistance thermometer the temperature of a duct adjacent to the cable which is the source of heat. In uncovering the conduits and exposing them to air, as a remedy for hot spots in the cable, it was found that the adjacent earth was hot and dry so that it crumbled to powder. This suggested opening a ditch in the ground above the conduit and directing a stream of water through it. This was found to lower the temperature immediately several degrees. Where an open conduit was not practical, water was discharged in to a vacant cable duct by means of a hose and this was found to be more effective than the open ditch method.

These experiments led to the installation of a line of porous tile duct in the earth above the conduit, surrounded with clean sand. The leakage of water through the pores of this duct has been found very effective in reducing the temperature of the cables. Whenever the temperature of the cables is found by exploring with a resistance thermometer to approach the danger point, water is turned into the porous drain tile, and the temperature is taken on successive days to see whether the desired reduction has been obtained. In this way one or two men, with resistance thermometers attached to long leads, can keep track of and control the temperature of the cables in a large system. No breakdowns of insulation of cables have occurred due to high temperature since the adoption of this method.

THE PURPOSE of this paper is (1) to describe a convenient method adopted by The Niagara Falls Power Company of determining the temperature of the insulation of underground cables carrying load; (2) to present the results of some field investigations made to determine the temperature of the earth and distribution of heat therein adjacent to underground cables; (3) to show the effect on the temperature of introducing moisture into the earth; and (4) to describe methods that were devised for supplying moisture where needed to reduce the temperature and thereby increase the carrying capacity of

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cables. The data herewith submitted were taken in the field for a practical purpose; consequently there was no justification for the refinements of laboratory measurements.

(1) It is not practicable to measure directly the temperature of the insulation of a cable at the surface of the conductor, without resorting to apparatus that is not suitable for general use over a cable system. For practical purposes, however, the temperature of the conductor can be obtained by exploring with a resistance thermometer the temperature of a duct adjacent to the cable that is the source of the heat. As we are principably interested in maximum temperatures, a cable should be selected for this purpose that is most unfavorably situated for radiation of heat. This cable can usually be selected by inspection. If the cables are situated as in Fig. 5 and temperatures are taken in duct marked *T*, the temperature of the insulation at the surface of the conductor is taken from a curve that applies to that particular cable. Fig. 1 is the curve for a 3/0, three-conductor, 11,000-volt cable, and Fig. 2 is the curve for 1,250,000-cir. mil, 2200-volt cable. For example, if a 3/0, three-conductor, 11,000-volt cable is carrying 170 amperes and the temperature of the adjacent duct *T* is 39 deg. cent., the temperature of the insulation at the surface of the conductor is 72 deg. cent. These curves are deduced from a formula given by Messrs. Atkinson and Fisher in a paper presented in 1913 and published in Vol. XXXII of the A. I. E. E. Transactions, page 325.

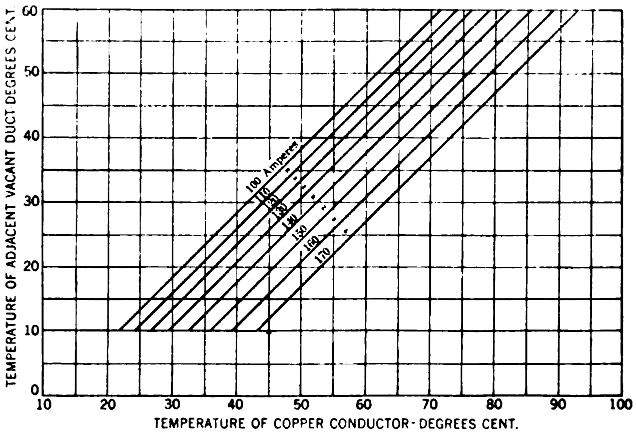

Fig. 1—3/0 Three-Conductor 11,000-Volt Paper and Lead Cable

The temperature at which paper-insulated lead-sheath cable can be operated safely has been carefully investigated, particularly by Mr. Henry W. Fisher. Some of the results of his investigations are given in the paper above referred to and in Foster's Handbook and the Standard Handbook. The maximum safe limiting temperature of paper insulation at the surface of the conductor in a cable, as stated in the Standardization Rules of the A. I. E. E., is 85 deg. cent. less a number of degrees equal to the kilovolts at which the cable is operated. In the case of a three-conductor, 11,000-volt cable, the limiting temperature of the insulation at the conductor is therefore 74 deg. cent., and in the case of a 2000-volt cable the limiting temperature is 83 deg. cent.

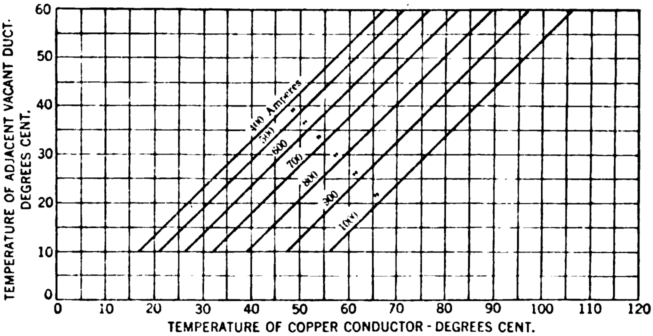

Fig. 2—1,250,000-Cir. Mil Single-Conductor 22,000-Volt Paper and Lead Cables

It was decided to adopt 66 deg. cent. as the maximum temperature for continuous operation of 11,000-volt paper-insulated cable, and 75 deg. cent. as the maximum temperature for continuous operation of 2200-volt paper insulated cable. This is eight deg. cent. lower than the safe limiting temperature specified in the Standardization Rules, which are based on fluctuating loads with peaks of short duration.

(2) To get some idea of the seasonal variation in the temperature of the earth, readings were taken each month in the year at a point about three ft. below the surface of the earth. This point was chosen near a section of conduit where overheating of cables had occurred, but at such distance that it was practically unaffected by heat from the conduit. In Fig. 3 the lower curve shows the seasonal variation in the

temperature of the earth. The upper curve shows the temperature variation three ft. below the surface of the earth, above a conduit containing cables. Fig. 4 shows the distance to which the earth surrounding a conduit is affected by heat from cables.

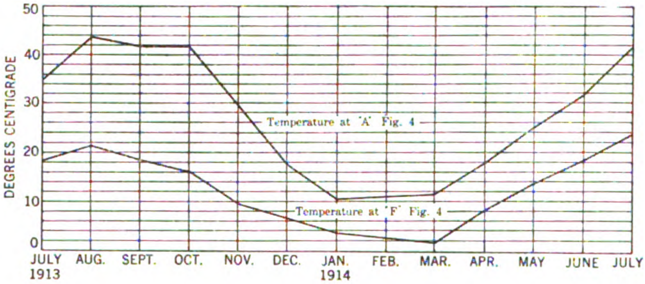

FIG. 3

The measurements were taken at different seasons of the year under approximately identical load conditions. The results indicate that parallel conduits must be at least thirty feet apart in order that the heat from one of them shall not appreciably affect the other.

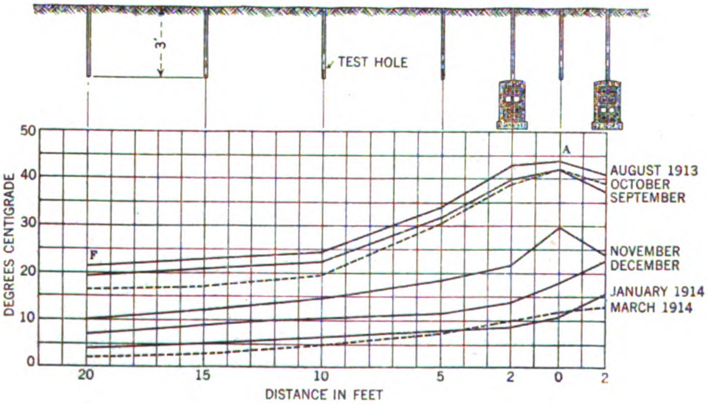

FIG. 4

(3) An effective remedy for hot spots in cables is to unearth the conduit and expose it to the air. In uncovering a conduit directly after a cable breakdown, it was found that the adjacent earth was very hot and so dry that it would crumble to powder. This condition suggested digging a ditch a few inches deep in

the ground just over and along the length of the conduit and directing a stream of water through it, as irrigation for crops is carried on in the Western States. This remedy immediately lowered the temperature of the cables several degrees. Where conduit was under roadways and paved streets the open ditch method was not available, and at these points water was discharged into a vacant duct by means of a garden hose. This was found to be even more effective than the open ditch method. In some cases, however, where multiple duct was used the water would not flow from one manhole to another, being lost on the way. Fig. 5 shows the effect on the temperature of cables of water discharged in a vacant duct. Two and a quarter gallons per minute reduced the temperature 13 deg. cent. and held it about constant. When the amount of water was increased to twelve gallons per minute, the temperature was reduced 13 deg. cent. further and then became constant. The remainder of the curve shows the gradual rise in temperature after the water was shut off.

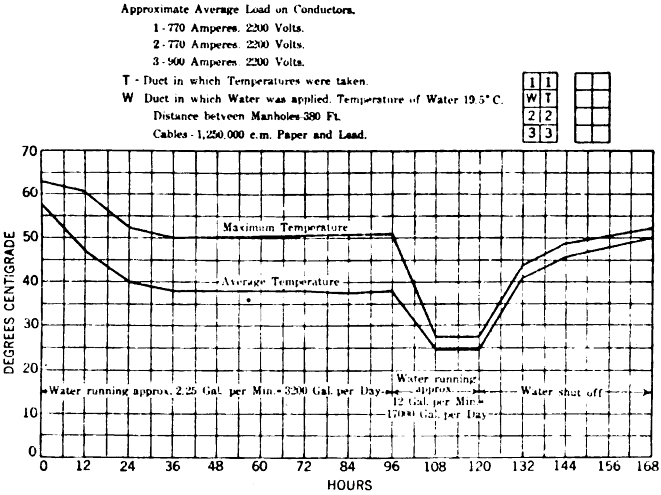

FIG. 5

(4) These crude methods of reducing the temperature pointed the way to a permanent installation to control the temperature of cables in conduits. The method finally adopted is shown in Figs. 6 and 7. Porous drain tiles four inches in diameter were made in sewer pipe moulds. These were laid in a trench in the

earth above the conduit, as shown in cros-ssection in Fig. 6. The joints were cemented to prevent leakage except through the pores of the tiles. This tile serves a purpose exactly opposite to that for which drain tile is generally used; that is, water is supplied through it to the surrounding earth, instead of being conducted away. The first experiment indicated that it might be difficult to get tile porous enough to exude a sufficient amount of water effectively to moisten the earth. This test was made with tile lying on the ground exposed to the air. After some experimenting it was found that the amount of water that would pass through the pores of the tile could be greatly increased by a covering of earth. Clean sand around the tile was more effective in producing the desired result than any other material tried.

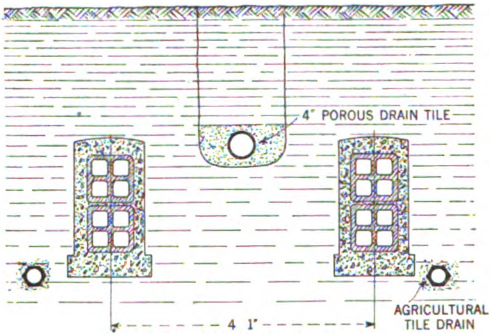

FIG. 6

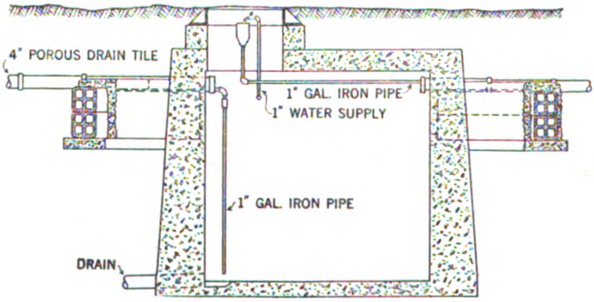

FIG. 7

In Fig. 8, curve *A* shows the distribution of heat in the earth at right angles to a line of conduit containing 2200-volt cables before water was applied by the drain tile method. Curve *B* shows the temperature after three gallons of water per minute had been applied about thirty-six hours.

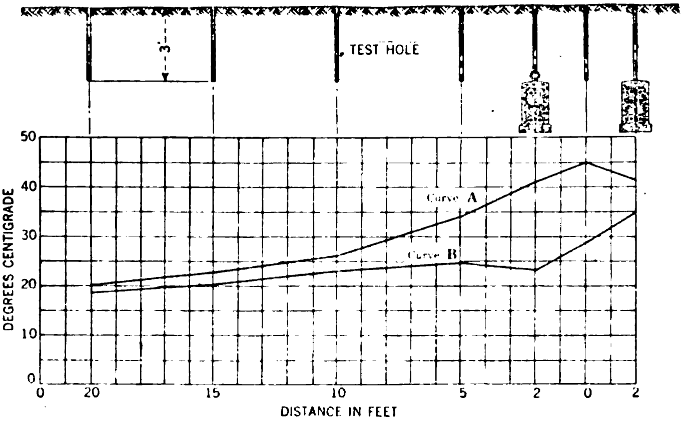

FIG. 8

It has been maintained by some that cables will run cooler in conduit surrounded by earth than in conduit surrounded by air. In Fig. 9 the upper curve shows temperatures obtained

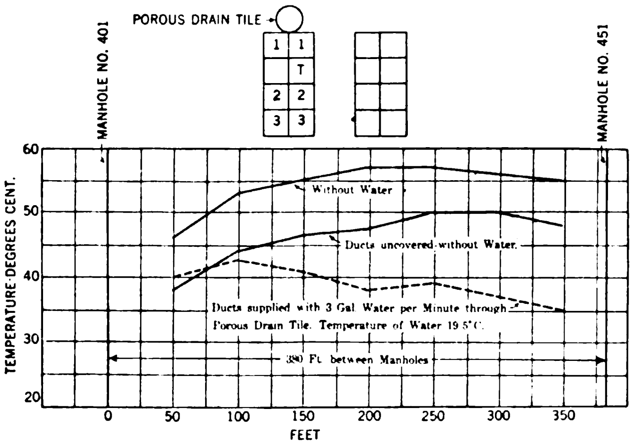

FIG. 9

in duct indicated by letter *T* before any effort was made to reduce the normal temperature. The middle curve shows temperatures obtained in the same duct after the top of the conduit had been unearthed. In this case the sides of the conduit were still covered with earth. The temperature of the air at the time of this test was about 16 deg. cent. The lower curve shows temperatures that were obtained after the drain tile had been laid, the earth replaced, and three gallons of water per minute supplied continuously for moistening the earth. The current on the cables was practically constant throughout the interval covered by these tests.

In practise the work of looking after the temperature of the cables is as follows:

When the season of the year arrives when overheating may be expected, a man is sent around with a resistance thermometer to explore the temperature of the ducts. If he finds the danger point is being reached or even approximated, water is turned into the porous drain tile. The following day the temperature is again taken to see whether the desired reduction has been obtained. In this way one or two men with portable resistance thermometers attached to long leads can keep track of and control the temperature of cables in a large system. Since this plan was adopted no breakdowns in insulation of cables have occurred due to high temperatures. The plans for installing the porous drain tile for cooling have been adopted as a standard, and whenever new conduits are laid in which high temperatures may be expected, the conduit will be provided with this means of cooling.

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the American Institute of Electrical Engineers,
New York, February 17, 1915, under the auspices
of the High-Tension Transmission Committee*

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OIL CIRCUIT BREAKERS

NOTES ON ARC PHENOMENA AND TENDENCIES IN DESIGN

BY K. C. RANDALL

ABSTRACT OF PAPER

The purpose of the paper is to present a brief explanatory discussion of some of the arc phenomena in oil circuit breakers and to describe the present tendencies in oil breaker construction and practise. A proposed method for rating breakers and specifying is included.

IN AN alternating-current arc formed in an oil breaker, opportunity is afforded for cooling and condensing the arc gases as the current passes through zero, and if these are completely condensed or removed and replaced by sufficient oil distance, the current will not be reestablished, because the medium intervening between the separating contacts has been changed to an insulator of sufficient dielectric strength to withstand the potential tending to reestablish the current. If the separation of contacts is not sufficient, or if the condensation and removal of gases is not adequate, or if the arc contained volatilized metal from the contacts, of sufficient quantity, the current will be reestablished. With an ideal oil breaker the current will not continue after the first zero value following the first complete separation of contacts.

In actual practise, on large powers, possibly few breakers comply with this ideal, because the current continues beyond the first zero value, due to (1) insufficient separation of the contacts; (2) large amount of gas formed in the arc; (3) reduction of insulating value of oil between contacts owing to suspended metal and carbon particles condensed after each successive half-cycle arc. If the particular breaker application is too far from the ideal the reestablishment of current after the first and subsequent zero values will continue indefinitely, or at least be repeated so many times that the breaker will be damaged or destroyed. Usually, in such instances, it is a case of misapplication or failure to main-

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tain initial conditions, for every breaker has its limitations within which it is good, but there may be a wide difference in rupturing capacity of breakers of given cost and space requirements, and it is by these differences that the better breakers are distinguished· Increase in capacity of a system, failure to maintain breakers either as to mechanism or insulation, change of current limitations, changes in methods of operation, faulty relays, etc., all may act to increase the duty on a breaker, even to destruction.

Plainly, it will be very difficult to interrupt an alternating current abruptly during any half cycle, for the same reason that an abrupt rupturing of a field current of a generator is difficult or dangerous. So it is that the endeavor of the breaker is focused upon providing against the reestablishment of current after normal zero value. Clearly, each time the current is reestablished and continues to the next zero value, energy is dissipated in the breaker tank, due to the arc. The oftener this is repeated the more the contacts are burned, the more the oil deteriorates, and the less the chance is of finally interrupting the current.

Assume a breaker, operating on a 15-cycle circuit of a given current and voltage, begins separation of contacts just as the current is normally passing through zero, and that the separation of contacts (acceleration) is such that the current ceases at the next zero. This same breaker operated in the same way on a like 60-cycle circuit will dissipate the same energy, if the current is of like volume and continues for the same time; that is, ceases at the fourth zero point. But, had the breaker been accelerated to prevent re-establishment of the current after the first half (60 cycles), the minimum energy could have been dissipated. Similarly, on 30 cycles, the speed of opening should have been twice that for 15 cycles; and in general, the rate of contact separation should be proportional to the frequency of the system when endeavoring to attain the ideal condition of terminating current at the end of the first half cycle.

The extinguishment of the arc will be near the normal zero point regardless of the speed of opening, because, whatever the rate of separating the contacts may be, tending to rapidly insert a dielectric in the form of cold oil, a potential tending to maintain the circuit current will be developed, and this, in general will be adequate to break down the intervening dielectric. Thus the current will be sustained until practically its normal zero point is reached. This will be true even if the whole breaker travel were accomplished in, say, $\frac{1}{8}$ or $\frac{1}{3}$ cycle; the current would still continue to practically the normal zero point, as each higher rate of current reduction gives a correspondingly higher sustaining voltage for maintaining it.

Furthermore, neglecting the voltage peaks required for reestablishing the current, the maximum steady voltage attainable across an arc is limited, regardless of the length of arc or current volume, and hence, the same loss is developed regardless of the rate or length of opening, provided the current and time of arcing is the same. This is explained as follows: With practically any current encountered in serious breaker problems, the ionization in the arc space will be quite complete and, therefore, it will constitute an excellent conductor, becoming better as it is further heated by increased currents, so that the drop will remain practically constant independent of the current volume provided it does not fall sufficiently to threaten deionization. The distance between contacts when the arc space is completely ionized has very little effect on the drop across it, provided the currents remain large as in ordinary breaker practise. This, therefore, demands for the best breaker results, that the speed and length of opening be such that current may never be established after the first zero value of current following the separation of the breaker contacts.

From the preceding, it is plain that on low frequencies an arc enduring to the first zero value following the separation of contacts will, on the average, continue for a longer period, and therefore dissipate more energy than an arc of like current but of higher frequencies, also extinguished at the first succeeding zero value. Therefore, in general, the high-frequency currents will be interrupted with the smaller demonstration and lesser breaker duty than similar lower frequency currents, and the energy dissipated will be, on the average, for an ideal breaker, about inversely proportional to the frequency.

After fixing the proper design of conducting details, allowing liberally for the continuous current-carrying capacity and for insulating distances—dielectric strength, such that liberal tests are successfully withstood—the problem of rupturing capacity still remains. On the higher potentials the insulation problems largely govern the dimensions. On the lower potentials mechanical considerations may largely dominate.

Oil, being the accepted insulating medium, convenient because of its dielectric value and liquid form so well suited to cooling and replacing arc gases, should, particularly on higher potentials, be of high grade. At the lower potentials the dielectric value of the oil is not so important. Some designs have been devised with the purpose of improving the circulation or agitation of the oil when the breaker operated so as to introduce fresh cool oil between the contacts thus sweeping away and condensing the arc products, and interposing a new clean dielectric which will not be punctured by the available potential tending to reestablish the current. Oils of low volatilization, slow carbonization and fair insulating value are desirable for average applications. For very low temperatures non-freezing oil should be used*, but these are usually so volatile at ordinary summer temperature that another oil must be used. A large oil volume is considered favorably, as through it the shock from the largely explosive action of enormous arc currents is reduced and absorbed. A large volume of oil will keep clean longer in a given service, and therefore maintain its insulation value better, besides initially affording better insulation distance. A large head of oil over the contacts means a heavier pressure on the arc bubble with consequent increased tendency to confine and quickly replace it with fresh oil. Facility of ionization of arc gases is decreased by higher vapor pressure, thus making reestablishment of the arc more difficult. The reduced volume of the gas bubble, due to the increased oil head, also disturbs the main oil body less, a very important matter when near the limit of rupturing capacity, especially of single-tank units.

The length of break is all-important, but if consideration of arc gases could be entirely eliminated, the length of break should only be sufficient to interpose an oil distance which would not be punctured by the available potential. As a rule, this would require but from 1 to 10 per cent of the actual travel available, as it takes 50,000 volts to puncture $\frac{1}{4}$ in. of moderately good oil. Therefore, the travel represents a very large margin over that indicated as necessary by the dielectric value of the oil alone; but it is necessary due to the reduced dielectric strength—in fact, conducting condition—prevailing during the arcing period. In a number of tests on a 25-cycle power circuit at 12,000 volts, about 15,000 amperes were interrupted at the end of a 4-in. travel (one-half cycle), although the contacts finally separated 9 inches.

An increased number of breaks in series, entirely neglecting method of accomplishment, would seem desirable, as the simultaneous opening of several breaks will accomplish the intervention of a given oil distance more rapidly than will a fewer number of breaks, assuming that the rate of contact separation remains roughly the same for both. With the increased oil distance, recovery after the first zero point is less likely. On the other hand, it is apparent that with the drop across each arc practically constant, the energy dissipated in the multi-break unit during the first half cycle will be roughly proportional to the number of breaks and greater than the fewer breaks. It probably will be considered better to tolerate this condition, with the assurance that the current will never pass the first zero, rather than contend with a design wherein the rate of breaking is not adequate to prevent repeated reestablishment of current after successive zeros. The deteriorated condition of the oil is considered more serious with a slow-operatingbreaker after passing several zero values, because of the longer arcing time, than with the design dissipating the same amount of energy but previous to the first zero value. A scheme to increase the arc voltage would not be welcome, but a plan to reduce it, and yet retain conditions opposed to current recovery after the first normal zero value is desirable, as in this way the total energy dissipated would be reduced. Whether a multi-break design is to be preferred over the usual break will be

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*Most oils are unsatisfactory below 0 deg. or −10 deg. fahr.

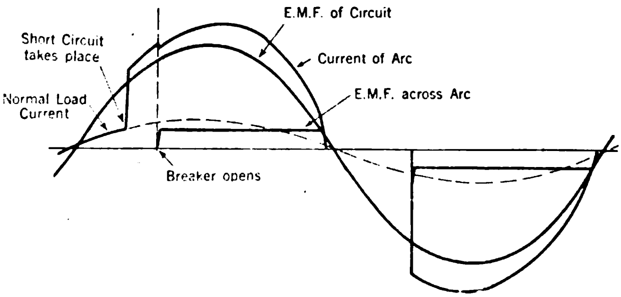


Fig. 1—Voltage and Current Curves for an Oil Circuit Breaker Arc in a Non-Inductive Circuit

The normal voltage and current of the non-inductive circuit are shown; also the sudden increase of the alternating current occurring at the moment of short circuit. Coincident with the breaker opening, a slight diminution in current volume is noted, resulting from the increased circuit resistance, due to breaker arc. The voltage across the arc is shown as a low practically constant value, developing at about the moment of opening and continuing until near the zero value when it becomes the circuit voltage, owing to the cessation of current. It continues along this curve until it has reached a value sufficient to puncture the dielectric between contacts, and thus reestablish the arc, when it again drops to the low practically constant value, shown in the first half cycle. The current follows practically the sine wave form until near the first zero, when, owing to reduced volume and consequent lowered heating, the arc gases are chilled and deionized, suddenly interrupting the current slightly in advance of the normal zero point. From here the current remains zero until suddenly reestablished in the opposite direction by the normal circuit voltage. This same cycle will be repeated until the contact separation becomes sufficient to prohibit reestablishment of current by the available circuit voltage.

decided by what may be accomplished by the common two break construction, when highly accelerated. It is plain that the additional mechanical complications and consequent larger masses of the multi-gap breaker that must be moved, will constitute a very serious problem.

Consideration of Fig. 2 makes apparent the general effect of self-induction on current interruption. On a non-inductive circuit (the current and voltage in phase) the chance of current reestablishment is much less probable than with an inductive circuit wherein—with lagging current—voltage is available for reestablishing the arc as the current emerges from the zero value. For this reason interruption of the current at the higher frequencies will be more difficult as the current lag for any given circuit is greater and the voltage tending to reestablish progressively more as the frequency is increased. On the other hand, the total self-induction of high-frequency circuits will usually be less

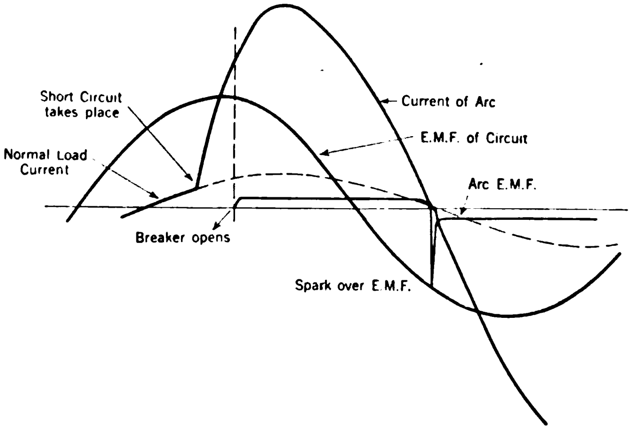


FIG. 2—VOLTAGE AND CURRENT CURVES FOR AN OIL BREAKER ARC IN AN INDUCTIVE CIRCUIT

The normal voltage and current in an inductive circuit are indicated and the development of the alternating current from the moment of short circuit with its decrease to zero and its later recovery in the opposite direction is shown. The voltage across the arc is also shown from the moment of breaker opening to near the normal current zero point where a high peak is developed which immediately drops to a low practically constant value, as shown in the first half cycle. Fig. 2 contrasts with Fig. 1 in that the current at the time of short circuit is established gradually, and passes through zero to a negative value, practically as a sine wave, this action being repeated at each zero point until finally at the last zero recovery is impossible. From the moment of the breaker opening the arc voltage develops almost immediately to a steady small value which holds until just before the first current zero. Here the current value has been so reduced that the lower rate of energy dissipation is no longer able to prevent chilling and deionization of the arc gases. Thus, the arc gases change suddenly from the nature of a conductor to the nature of a dielectric and tend to terminate the current with equal suddenness slightly previous to the normal zero point. This action is acknowledged through the self-induction of the circuit by a sharp voltage peak which breaks down the dielectric and is following by reionization within the arc space, whereupon the low arc voltage, as shown in the first half cycle, again appears. This same potential peak will occur at each successive zero until the current is finally terminated, when the arc voltage becomes the circuit voltage.

than on circuits of lower frequencies, and, therefore, the termination of the arc current will be facilitated. This is apparent, for in the endeavor to suddenly rupture the current, but little sustaining power is encountered in the practically non-inductive circuit, while in the highly inductive circuit every change in current is accompanied by a corresponding potential tending to maintain that current.

In the breaker arc, as chilling occurs near the zero value of current, the ionization of the gases ceases and conductivity in the arc space is so reduced that the current can only be established by a potential capable of puncturing the resulting dielectric which has become very much stronger than it was previous to deionization. Very high arc currents, with their correspondingly high temperatures and increased volume of arc gases, make deionization much more difficult, thus rendering the successive reestablishment of current much easier. The enormous energy dissipated by very large currents as the contacts first separate is a demonstration of an explosive character. Breaker tanks have been blown off with practically no contact burning, evidencing a violent pressure of short duration. So it is that larger currents are more difficult of interruption.

Facility of deionization of the arc gases will depend upon the temperature and pressure of the surrounding oil, and the shape and volume of the contacts, and also on their heat conductivity and vaporizing temperature. Plainly, contacts of small volume with sharp edges, low heat conductivity and low vaporizing temperature are least favorable to the breaker. From this it is apparent that a small breaker, on the score of volume and shape of contacts alone, is more severely tried than a larger unit. This plainly emphasizes the desirability of large contacts of smooth shape.

Gravity-actuated breakers never open quite as rapidly as a free falling body, and sometimes the retarding influence of the mechanism is very serious, so that accelerating devices are now common, and the rate of opening is in many breakers much more rapid than that obtainable from unimpeded gravity alone. The matter of stopping the moving parts as they approach the end of the stroke has to be carefully considered, in the case of larger breakers, even when unaccelerated, but when highly accelerated the problem is more serious and may even be complicated. Fast closing is important like fast opening. An explosive action is likely as the arcing tips of a slow-closing breaker touch when closing against a short circuit, due to the violent energy dissipation and consequent volatilization of contacts and oil. This action is identical with that occurring in as low-opening unit. Modern practise, particularly on the score of general simplicity, favors the solenoid operation for all remote-controlled oil breakers save when manually operated.

Tending to limit the maximum capacity that may be ruptured by a single plain breaker, large current volumes are the most serious problem because of their practically explosive action. As the operating voltage increases, the available currents decrease proportionately, but the difficulty of the problem is not much improved until rather high potentials are reached when the distances necessary for obtaining a proper margin of safety for insulation and test afford relief from mechanical shock encountered in the designs for lower voltages. Probably the maximum power that plain breakers as now built could rupture will approx-

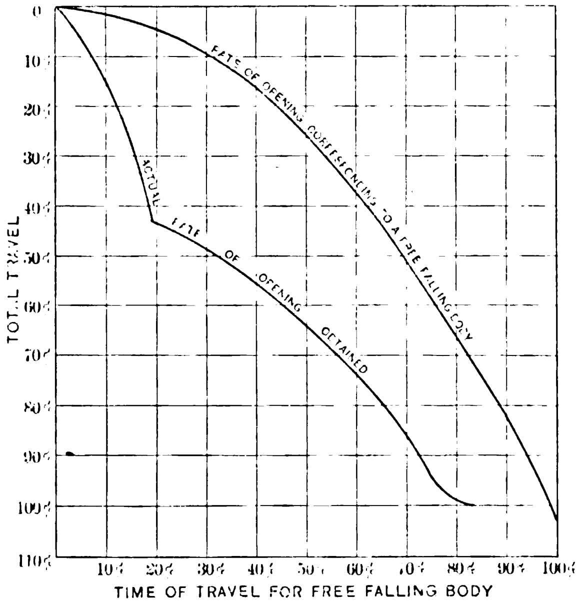
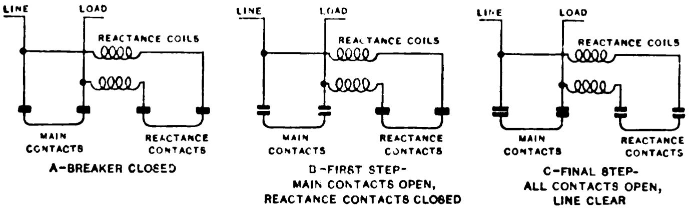


FIG. 3

This figure shows the curve of a free falling body, which is the best that a plain unaccelerated breaker can do. It also shows the actual rate of opening of a specially accelerated breaker built for extra high voltage service. The unusual acceleration in the first 40 per cent of the travel is obtained by a retrieving contact which is drawn out by the already highly accelerated main contacts and then suddenly retrieves while the main contacts continue to near the end of the stroke, where they are retarded and the blow from their fall absorbed.

imate the power that would be delivered through a shunt-tripped breaker at the time of opening, by 150,000 kv-a. of modern high-reactance generators on a single bus, feeding a maximum short circuit, so that the current is limited only by the generator impedance. In general it will be easier to handle the given short circuit at, say, 15,000 volts, because at higher potentials the chance of reestablishment may be greater, while at lower potentials the volume of current would seriously increase the total amount of energy to be dissipated in the arc, and therefore the difficulty of terminating the current. A breaker adapted to such a station for 15,000-volt service is illustrated in Fig. 6, and is constructed with particular regard to obtaining the strong tank and supporting details, so that even with violent energy dissipation in the arc, the mechanical details will withstand the shock. This breaker will require for installation, a space approximately 7 ft. 4 in. by 2 ft. 1 in. by 9 ft. high.



A-BREAKER CLOSED

B-FIRST STEP-
MAIN CONTACTS OPEN,
REACTANCE CONTACTS CLOSED

C-FINAL STEP-
ALL CONTACTS OPEN,
LINE CLEAR

FIG. 5—TERMINAL AND CONTACT ARRANGEMENT WITH REACTANCE COILS OF HIGH, VOLTAGE REACTANCE BREAKER

Sequence of operation of breaker shown in Fig. 4.

In endeavoring to raise the limit of power to which plain breakers may be applied, without employing permanent current-limiting reactance, originally the resistance and later the reactance breakers were developed. Initially, as is fairly well known, the design took the form of a resistance with a number of contacts, each one introducing more resistance into the circuit, and the last opening the circuit. This was later simplified, making but two steps, the first introducing a considerable resistance, and the second opening the circuit. Because of difficulties in the design and application of resistance, reactance was substituted, and a considerable number of such breakers has been built. The reactance breaker followed the form of the later resistance breakers, in that two steps were employed; one to introduce the current-limiting reactance, and the second to open the circuit. The reactors are designed to carry current but a very short period, as the time between introducing them into the circuit and final rupturing of current is very short—considerably less than one second. In this way a small conductor of many turns affords in small space a very considerable reactance. A still later development of the reactance breaker idea has somewhat simplified the matter. Instead of employing interlocked mechanism, such that the first mechanism introduces the reactors, and the second opens the circuit, two similar breaks are now employed operating simultaneously from a common mechanism—one of which is shunted by a reactance coil. It is well known that the shunted arc is inclined to be unstable, and in actual test it has been found that the shunted breaker does its duty promptly and with very little effort. The final break, of course, will only involve the current permitted by the limiting reactance. This will be easily terminaated, so that with this arrangement the shunted pole will probably only arc to the first zero—not reestablishing—and the second pole will not arc beyond the second zero, even though the circuit be highly inductive, because of the limited current which it has to interrupt. This arrangement is very simple as to mechanism, permits the employment of the standard breakers and allows mounting the current-limiting reactors wherever it may be convenient in the installation.

For some time breakers were supplied according to the judgment of the designer of the equipment, or according to the ideas of the purchaser. No definite plan of rating or determining capacity existed. Later, more attention was paid, especially to installations on the large powers, and some approximations were made, as to what the proper rating for the breaker should be. Now, installations are quite generally receiving individual consideration in the breaker applications, and the desirability of a uniform method of rating is growing constantly more pressing. A method, developed from experience, tests, and consideration of common problems, assumes the breaker to be installed directly on the bus and to protect same against nearby short circuits. In determining the maximum breaker duty a generator equipment of 8 per cent impedance—capable of delivering 12½ times normal current at the first instant of short circuit, is assumed. It is also assumed that by the time breaker opening occurs, this maximum current value will have decreased to one half the initial, namely, to 6¼ times normal. In this way, when a breaker design has been fixed as capable of rupturing a certain current at

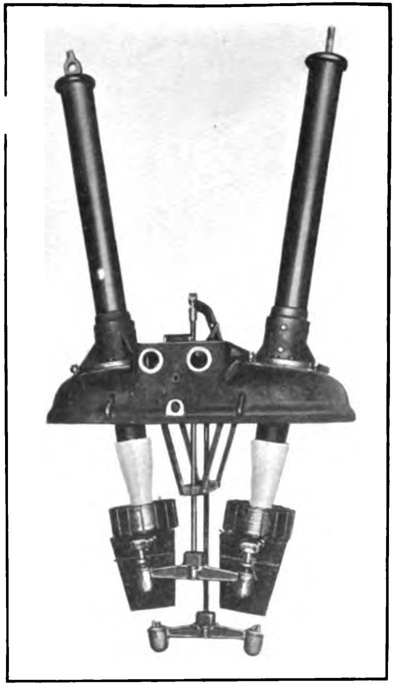


FIG. 4 [RANDALL]

Illustrates internal arrangement of 100,000-volt reactance breaker. Main contacts, having separated, and reactance coils, one concentrically mounted on each terminal, are in circuit. Final break is about to take place. Barriers separating main and breaking contacts are shown projecting below reactance coils. Sequence of operation is indicated in Fig. 5.

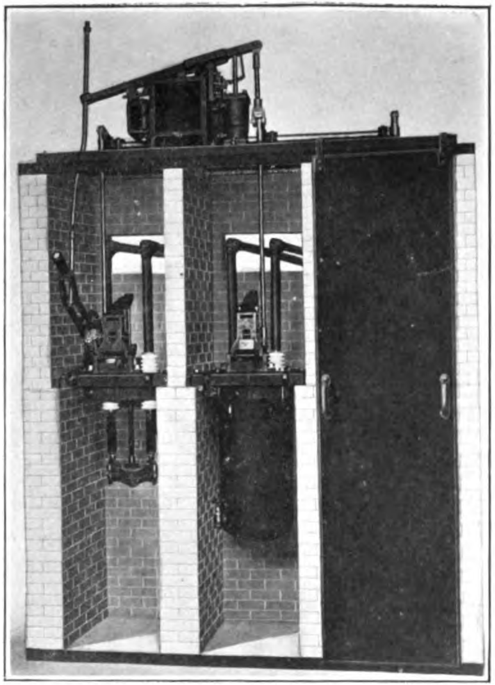


FIG. 6 [RANDALL]

Shows breaker intended for duty on high power system and is adapted to potentials up to 35,000 volts. Note arrangement of mechanism above, incorporating combined accelerating and retarding device as described in Figs. 7 and 8. This breaker illustrates present tendency in the extra strong one-piece drawn tank; heavy supporting bolts with steel fittings for same; provision for high acceleration vented air chamber above oil; oil level indicated by gage glass, vent obscured by mechanism; readily replacable arcing tips of liberal dimensions; individual pole units operated from single mechanism through common shaft.

a certain voltage, the kv-a. rating of the system to which it may properly be applied is one whose normal current rating is obtained by dividing the breaker current rating for the particular voltage by $6\frac{1}{4}$. Thus, a breaker rated at 160,000 kv-a., three-phase, 44,000 volt contemplates 2100 amperes per phase in the arc and may properly be applied to a station having a normal current of 335 amperes, 44,000 volts three-phase. All of this contemplated instantaneous tripping. If time tripping is employed so that the current may have decreased to some smaller multiple of the normal value, application may be made to a still larger station, provided always that the maximum current to be terminated does not exceed the maximum volume given (in this case 2100 amperes). The time to reach the sustained short-circuit currents will vary widely; possibly from 15 to 50 cycles on 60-cycle systems, and from 5 to 20 cycles on 25-cycle systems. With time elements set for these periods or longer, the maximum duty on the breaker will approximate interrupting double current, and in general, for such installation the capacity of the plant may be at least doubled as against the safe application on instantaneous tripping.

The best method of specifying breaker equipment for a given service is to indicate the duty which the breaker will be expected to perform by giving the maximum current that it may be called upon to interrupt, as well as the service voltage. It will be recognized, when this is done, that the source of power, method of tripping, or location on the system is immaterial, for all of those considerations are covered when the value for the maximum current is fixed. Some installations and classes of service may not warrant employing a design which will satisfactorily and repeatedly handle the worst short circuit currents. For such installations, when the extreme maximum currents are very improbable and it is not desired to allow them, the usual maximum current which the breaker may be called upon to interrupt should be taken as the basis, and a breaker of such rupturing capacity specified.

The present tendency in circuit breakers is largely to improve mechanical details. Insulation of designs has generally been adequate. Among the notable mechanical features found in modern breakers are: (1) Increased strength of tanks with supports and fittings so as to safely withstand the shock of rupturing large powers. (2) Rapid acceleration of breaker so as to obtain high rates of contact separation with the attendant early termination of arcs, and consequent reduced energy dissipation. (3) Provision for vented expulsion chamber over the oil from which gases may escape, without entraining much oil, thus reducing the high and otherwise destructive pressures occurring in heavy duty.

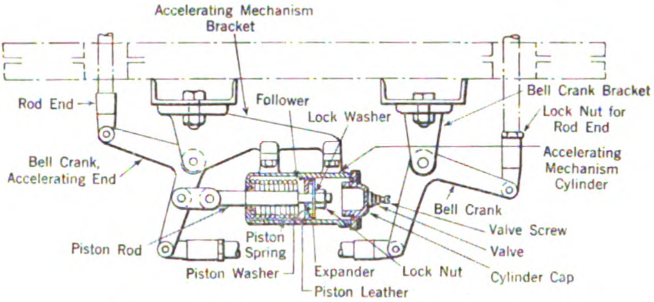


FIG. 7

This mechanism illustrates an arrangement commonly applicable to remote manually or electrically-operated breakers, and consists essentially of a spring for accelerating the opening of the breaker, with a plunger in a cylinder for retarding and bringing the moving contacts to rest without shock at the end of a stroke.

(4) Arrangement for liberal and easily replacable contact parts of minimum cost, in even small as well as larger capacities. (5) Employment of larger capacity (single) pole units, suitably assembled, and operated from a single separate mechanism, instead of using multipolar units assembled with individual mechanisms.

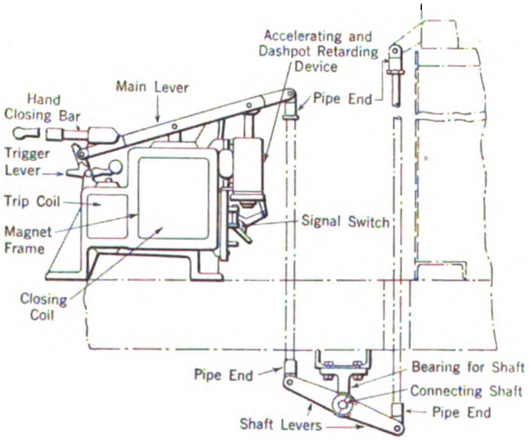


FIG. 8

This figure illustrates a typical solenoid mechanism for operating electrically controlled breakers, and incorporates the accelerating and dash pot devices shown in Fig. 7.

In existing practise, wide differences are found, and operating engineers sometimes seem to have almost opposite opinions. In one installation a breaker discharging a very small volume of oil accompanied by some smoke under the most severe conditions was considered as a hazardous application. On another system blowing off of breaker tanks was considered fairly serious, but principally because of the difficulty in replacing the distorted tanks. Mere discharges of smoke, oil, or distortion of the tank were looked upon as of trifling consequence, so long as the apparatus remained in operating condition. This brings up the question, frequently arising, "when is a breaker satisfactory for a given service?" One reply advocated that if the unit may immediately be put back into permanent satisfactory operation without immediate repair, it is proper for the particular application.

DISCUSSION ON "ENGINEERING DATA RELATING TO HIGH-TENSION TRANSMISSION SYSTEMS" (SUB-COMMITTEE REPORT: THOMAS), DETROIT, MICH., JUNE 25, 1914. (SEE PROCEEDINGS FOR OCTOBER, 1914.)

(Subject to final revision for the Transactions.)

John B. Fisken: On page 1457 it is stated for the Washington Waterpower Company, "We have noted no deterioration in conductors." That, as far as I know, was true up to within the past few weeks. Since I left home I have been advised that a very serious deterioration has been noticed in some of the conductors. I have a small sample of wire here which was sent to me at Detroit, which I will give to the chairman; it shows the deterioration to which I refer. I do not know what the cause is, and I cannot account for it, unless it is a corona effect. It appears to be a very serious matter. This line has been in operation about eleven years. The first eighteen months it was operated at about 45,000 volts, and since then at 60,000 volts. The triangle is 42 inches. The insulators are carried on iron pins and wooden poles, and until about two years ago the pins were not grounded. At that time we did ground the pins and that has had some effect on the wire, possibly. I merely call your attention to this to show that we at any rate have found deterioration in the conductors.

Percy H. Thomas: There is a marked deterioration in the wire; a wasting away in spots of the metal at least 1/16 in. deep. We are greatly indebted to Mr. Fisken for bringing this point forward, and it is a matter that we should all bear closely in mind. What part of the system was this taken from, and what were the conditions surrounding the line at that point?

John B. Fisken: The climate is such that for about two months in the summer there is practically no rain. The average annual precipitation is about 22 in., and the elevation where that wire was taken down was about 2500 ft.

Percy H. Thomas: Was this deterioration noticed generally over the system, or at some particular location?

John B. Fisken: We have only gone over a few miles of the line, and it has been noticed all over that portion. This matter has only come up within the last month, so we have not had time to make a full examination of the rest of the line, which is about 100 miles long.

S. C. Lindsay: The Committee states that there were only a few companies using protective relays, and that the Puget Sound Traction, Light and Power Company does not state the result of selective action. When the data were compiled we had only two lines equipped with reverse-power relays, and we had not had a case of trouble on either line since they were installed. The question of equipping our whole system with automatic relays had been thoroughly investigated, and the equipment was being installed when these data were supplied. Since forwarding these data to the committee we have had several cases of trouble, and on the whole are getting very encouraging results from our automatic relays on networks of lines. We have three networks, 50,000-, 13,000- and 2200-volt lines. Our relay installation is not complete at this time, but within the course of a year our company will be able to contribute additional data on the question of automatic relays for protecting networks.

Percy H. Thomas: The matter of protecting telephone lines on the same towers as high-tension lines, or even in the same general neighborhood and paralleling high-tension lines, is a most important one. There are two difficulties encountered, the difficulty of talking and hearing, and the danger to the operator.

The difficulty of talking is due to electrostatic, and; to some extent, electromagnetic, induction between the high-tension line and the telephone line. It is of course the long parallelism between them that makes the situation serious, on account of the very great sensitiveness of the telephone. The telephone line is so sensitive to this disturbance that putting the telephone line a mile away from the power line will not prevent interruption of telephone service under most conditions whenever the power line is grounded or short-circuited, or by the charging of electrolytic arresters, or almost any kind of electrical disturbance.

If the telephone line is a mile away and has not protective means, talking is usually impracticable when the power line is upset from any cause. It is relatively easy, however, to protect such a telephone line so that talking is good, for example by the use of drainage coils. The drainage coil is a transformer winding connected between the two telephone wires and having its middle point grounded.

The characteristic of the voltage disturbance produced in a telephone line by the power line, which distinguishes it from the useful voltage in the telephone line producing the talk, is the fact that induction from the power line affects both telephone wires alike. If the induction is such as to raise the potential of the telephone wires they are both raised at once, and if it is such as to lower the potential they are both lowered at once. Talking through telephone wires, on the other hand, produces potentials positive on one telephone line and negative on the other. The power disturbance raises them or lowers them together. A device which will prevent a change of potential of the same sign in the two wires, but will permit potentials of opposite signs to exist in the two wires, gives the desired result of permitting talk and resisting induction. The drainage coil does just this. The induced currents which tend to flow to ground at the same time from the two telephone wires are unimpeded, since the magnetic effects in the windings will neutralize each other, and will not produce any magnetism in the core of the transformer. Therefore, the only impedance to ground they meet is due to the resistance of these windings and to whatever magnetic leakage there may be between the two halves of the winding.

Obviously, the disturbance produced in the telephone wires by the power line is of such a nature as to send a charging current into, or out of, the two telephone wires at the same time. If no charging current can flow, the induction affects the potential of the two wires. With a connection to ground, the effect of the disturbance is to produce charging current in the two wires.

It is impossible to eliminate absolutely the resistance offered by the drainage coil to the charging current to ground, but the residual 50 or 100 volts, of course, is immaterial. The one precaution to observe with this kind of protection is to make sure that there is no condition in which the power line disturbance can produce so large a charging current to the telephone wires through the drainage coils as to burn them out.

Where the exposure of a telephone line to a high-tension line is a good many miles, it is good practise to have a number of these drainage coils, so if anything happens to one, others will remain and protection at any one point does not depend on a coil a hundred miles away.

So much for the first type of disturbance of the telephone line, and drainage coils, properly installed, are pretty nearly sufficient for protection.

The second type of disturbance is the danger to operators. The 1 to 1 transformer is certainly a very great protection, but remember this—they are generally tested at not over 25,000 volts, which is hardly sufficient, on a 100,000-volt system, to give absolute protection. It is desirable to have spark gaps and fuses as well.

The insulating transformer very materially cuts down the transmission of speech. It is not possible to speak as clearly through the insulating transformer as if the transformer were not there.

Ernest V. Pannell: In view of the very valuable data given in this report, it is scarcely fair to criticise its lack of completeness, but I think it would have been more interesting if it had been possible for the report to show how the design of the line is influenced by the conducting material used. In going through this list of transmission lines, it is notable that 40 per cent of them are using aluminum conductors to a greater or less extent. In addition we see a metal in use which I believe is copper-clad steel, and also steel-core copper and steel-core aluminum. Now if we had a thorough and exhaustive report, comparing these various materials side by side, with their advantages and disadvantages, and the various experiences in operating them, it would, I am sure, fill a very wide gap in our practical knowledge of transmission line design at the present day.

With particular reference to long spans, of course this is the incentive which has brought most of these high-tenacity materials into use, and in this connection it has frequently been said that aluminum is good for spans which do not exceed six or seven hundred feet. In view of the remarks of the Pacific Gas and Electric Company in this report, however, and of other companies operating with aluminum on their long spans, this seems no longer to hold good; and with the greater tenacity obtained in the present-day product, it would seem that aluminum is perfectly satisfactory on all spans which can be run with copper. An additional piece of information comes to my mind, and that is a transmission line recently erected in Norway, where they are putting on spans up to 2300 ft. in length, which are being made with cables of a light aluminum alloy having a tenacity of 36,000 lb. per sq. in.

Where a line has been designed for aluminum conductors as an alternative to copper, it does not seem to me that the correct principle is always followed. Almost invariably the aluminum conductors are chosen equivalent to the conductivity of the copper only. Necessarily, the aluminum will have a greater sag, and higher and more costly towers will be required. If, as an alternative, cables of larger area of cross-section were used, the tension on the lines could be increased, the sag decreased, and the towers, although they would have to be stiffer, need not be as high, and I believe the line would be more reliable throughout and at least as cheap.

If there is any information forthcoming on this matter of compound steel-copper and steel-aluminum conductors, it would be interesting to know just how the stresses are distributed in them. I take it, that where a steel-core is employed, instead of aluminum or copper, the lay of the steel is longer than that of the outer metal, so that it takes the major part of the pull.

The sample which Mr. Fisken showed to us was very interesting, and it appeared as if the trouble was due to abrasion rather than corrosion. I do not know whether anyone will bear me out in that. I will ask Mr. Fisken, in view of the fact that I believe he has some aluminum wire on his system, whether the aluminum conductors have shown similar trouble, or how they are behaving. It is a notable fact that under many atmospheric conditions which cause copper to deteriorate, aluminum has been found to operate satisfactorily.

Percy H. Thomas: What do you mean by a tenacity of 36,000 lb. per sq. in? Is that the ultimate strength of the elastic limit?

Ernest V. Pannell: That is the ultimate strength per sq. inch.

John B. Fisken: We took down about 50 miles of aluminum wire that had been in operation for about five years and nothing of this kind was found; whether it will be in the same condition after ten years, or not, I cannot tell.

Percy H. Thomas: Possibly some of you gentleman do not happen to have noticed that we have at least two or three long transmission lines which are using a special cable with a steel center, and a number of aluminum strands wound around it, the steel being very high strength steel, and the aluminum giving conductivity and giving large diameter to keep down corona.

I wonder if there is anyone present who can give us any further information about that steel-aluminum cable.

E. E. F. Creighton: I wish to say a few words about the vacuum lightning arrester which has been under development for a number of years, to have no misunderstanding of the limitations of its use. Mr. Emerson P. Peck has taken the initiative in applying this arrester to the protection of telephone wires situated on 11,000,- 22,000- and 110,000-volt lines of the Georgia Railway and Power Company. The lightning arrester was developed specifically for signal circuits of steam railways and it was intended in these circuits to make the arrester so that it would never short-circuit. A short-circuited arrester on a signal circuit means a false signal of safety, and therefore is very dangerous. This arrester was developed with that idea in mind, to avoid the danger of short-circuiting. As a result, the arrester will stand momentarily 1000 amperes of direct current at 600 volts, while a circuit breaker opens, without having its electrodes welded together—in fact, it will do this a number of times. Opening up an arrester after tests of that kind we found the electrode very much shrunken in size, but in no case was the electrode melted in such a way as to come in contact with the outer copper tube. I am not bringing this matter up at this time to describe the arrester, but to describe the limitation, and therefore I shall pass immediately to the point in mind.

While the arrester was developed to withstand heavy current for a brief time, it was not given sufficient cooling area to discharge a small current for a long time. It frequently happens that an accidental arcing ground occurring on a system lasts for a considerable length of time before it is removed. If this arrester is so placed that discharges pass through it during this period it is liable to be overheated and damaged. Mr. Peck has apparently found no trouble from this source, and it is probably due to the fact that continuous discharges do not take place for a long time through the arrester in the position in which it was used. An arrester having plenty of cooling surface can be made for this particular service and a few of them have been put out. I think the important point is that with the arrangement that Mr. Peck has used* it seems unnecessary to take the precaution of using a larger lightning arrester and a more expensive one in order to keep it cool.

In the matter of the damage done to the wire which Mr. Fisken showed, we have had in certain types of apparatus which we have built in the laboratory something quite similar that makes us think it is the same thing. An electrostatic relay in which an insulator was used to furnish the electrostatic pull produced just such corona, which formed nitrous oxide, and with the natural moisture in the air, formed nitric acid. This corona discharge, which was a little heavier than the blue discharge which gives ozone, was confined in a glass box. The nitrous oxide continued to increase in density, and as a result every one of the metal parts inside, except the aluminum, was very badly corroded. It would seem that this is the same thing that Mr. Fisken found, in that the wire is eaten out directly above the insulator where it lay on top of the porcelain, in the location where the corona would be the strongest. Taking into account the high altitude and the fact that the insulators were made many years ago, it would lead one to believe that the static charging current in that insulator might be sufficient to get the corona above the value which causes ozone, into that region of discharge where nitrous oxide is formed. One can easily determine visually the intensity of corona discharge which forms nitrous oxide. It is marked by the appearance of definite little threads or bright streamers in the otherwise uniform blue brush discharge.

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*October, 1914, PROCEEDINGS A. I. E. E., pages 1476-1480.

Percy H. Thomas: What Professor Creighton says certainly sounds very reasonable, and I want to ask Mr. Fisken if any of the insulators in this neighborhood are on wooden pins.

John B. Fisken: All iron pins.

Percy H. Thomas: Have you examined the tops of any of the pins—do they show any sign of deterioration?

John B. Fisken: No.

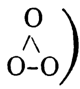
Percy H. Thomas: I should say the iron would be attacked by nitrous oxide if it existed.

John B. Fisken: We have taken off a number of pins and never noticed anything of that kind.

Percy H. Thomas: Are they set in cement?

John B. Fisken: No, in lead.

Percy H. Thomas: The digestion of tops of wooden pins suggests this same sort of action.

F. W. Peek, Jr.: The explanation of the brush discharge as the cause of the deterioration of the line conductor, which Mr. Fisken has shown, is undoubtedly the correct one. This occurs at or near the insulator. Where the wire is tied to the insulator there is the metal conductor, a thin film of air, a thickness of porcelain, and the pin. There is thus a condenser with the line conductor as one plate, air and porcelain in series as the dielectric, and the metal pin as the other plate. The voltage across this condenser is equal to line voltage divided by $\sqrt{3}$. The same dielectric flux passes through the porcelain to the air. The permittivity of air is 1 and of porcelain is 5. The porcelain "conducts" the dielectric flux five times as well as air. The voltage gradient in the the air film is thus five times what it is in certain parts of the porcelain. This air film breaks down as a brush. Air consists of a mechanical mixture of oxygen and nitrogen. The oxygen is O_2 $(O=O)$ and is inactive. In the brush it splits up as O. Recombination takes place as O_2 and O_3 (ozone, ). Both O and O_3 are chemically active and oxidize the conductors. At high gradients on the air, nitrogen also combines with the oxygen and in the presence of moisture forms nitric acid. This also attacks the conductor. Each insulator is a small ozone and nitric acid generator. It can be prevented by a properly placed corona shield.

Aluminum is affected to a much less extent by the above cause. Either aluminum or copper may, however, deteriorate very rapidly due to desulphurizing, and other mining processes.

Percy H. Thomas: I want to call attention to the fact that it is not excessive line potential, primarily, that breaks down the small air gap between the insulator and the conductor, it is the *fall of potential* across the air gap itself. With a small enough air gap, a low potential will produce this breakdown. Mr. Peek has spoken of a similar action in the windings at the end of the coils of the armature of a 200- or 300-volt generator, where a concentration of potential may under some circumstances be sufficient to produce this acetic or nitric acid formation, and deteriorate the insulation. The same thing occurs in rubber-covered underground cables where there is a great concentration of potential, and when the ends of the rubber covering are exposed to the air there is oftentimes a hardening or deterioration of the rubber due to oxidation from the formation of ozone. Those of you who use suspension insulators may feel secure in this matter with the idea that the insulators are connected to the conductor by a metal clamp, and no difference of potential can occur to form nitric acid on the conductor in the clamp.

R. Fleming: Regarding the action of nitric acid under atmospheric conditions, I do not remember having seen it proved very conclusively just what action takes place. It seems to me we have here an opportunity to get at least tentative proof as to what action takes place. It is surely chemical. On examining the sample of wire you will find there is plenty of deposit which would enable a chemist to analyze and determine its chemical nature. It is probably sulphate, it may be nitrate, or it may be carbonate of copper. The electric discharge alone would probably not disintegrate wire in the manner here shown.

H. H. Norton: I would suggest that a number of samples be collected and submitted for analysis to some chemist capable of performing such an analysis. It would require considerable work to do it. I ask Mr. Fisken if there are any smelters in the vicinity. Smelter fumes are likely to produce sulphates.

M. von Recklinghausen: I have examined this piece of wire, and to me as a chemist it looks strange that it is attacked deeply on two points. These are probably the points where the tie wire has touched this wire. There may be two explanations here—one is mechanical, but I do not think that is likely. The other may be electrolysis. The tie wire is not of the same metal, although both are supposed to be pure copper. Both are not pure copper. They are different in composition, and it is possible that there is some electrolytic action going on between the two and the humidity from the atmosphere. I offer that merely as a possible explanation. I cannot say, offhand, that that is the cause, but it looks to me very much as if such electrolytic action between the tie wire and the conductor itself could take place due to the humidity as an electrolyte.

F. W. Peek, Jr.: I want to answer the question which has been raised, and state that such an analysis has been made, though not on Mr. Fisken's cable. We have made analyses on other samples, and found a combination of nitrogen and copper.

D. D. Ewing: In looking over the samples of wire brought by Mr. Fisken, I noticed that the deposit of salt was heavier on the pole insulator wire than on the two arm insulator wires. It seems to me that this indicates that the corrosion is worse on the pole wire than on the arm wires. If such is the case, it does not look to me reasonable that it is a nitrogen proposition altogether.

I believe Mr. Fisken made the statement that for two months in the year there was no rainfall in the district traversed by this line. He did not say anything about the soil and dust conditions, but I would judge, if there is no rain for two months in the year, that it gets pretty dusty. If the soil contains either soluble organic acids, or inorganic salts, dust in combination with water might produce the corrosion. The salt looked to me like carbonate or sulphate, or possibly nitrate, although it is impossible to determine its exact nature by inspection.

R. E. Argersinger: I want to call attention to the report of the Pennsylvania Water and Power Company engineers on the operation of their system, particularly as regards the use of reverse power relays at the substation end of the line and inverse time limit relays at the generating station, and also to point out that they are doing automatic switching on the low-tension side of the transformers at both ends of the line. This matter is referred to on pages 1460 and 1461 of the report. This system includes a 70,000-volt line, about 40 miles long, two circuits in parallel on the same tower line, with neutral grounded through resistance. As the report points out, it is difficult to get a clear idea of the relay action, since the operation is complicated by the use of arc extinguishers and also field-destroying devices. The relays are set with a time limit so that the arc extinguisher will operate first in case of flash-over to ground, and if that fails to relieve the trouble the relays operate the switches only on the line affected, and the point is that they actually cut out the circuit in trouble without disturbing the parallel circuit and without interruption of service. It is interesting to note that a few other companies are introducing this system of operation. Mr. Lindsay says his company is going into it, but that they have not had much experience yet. In my opinion, this is one of the most important features to be considered in the layout of a high-tension transmission system.

In an article I wrote, published in the *G. E. Review* for June, 1913, this system of connections was described. In an elementary way such a system might be represented by the diagram in Fig. 1, herewith, which represents a generating station connected to a substation by two transmission lines.

The normal condition of operation would be to have all of generators in parallel on the bus *A* and all of the feeders in parallel on the bus *D*. The high-tension buses *B* and *C* would normally be opened by *S* and *T*. Switches *E* and *G* would be equipped with inverse time limit relays. Switches *K*, *P*, *R* and *M* would be non-automatic, and switches *F* and *L* would be equipped with reverse power relays. In case of trouble, then, on one line, say at *X*, the switch *F* would be opened by the reverse power relay. Switch *E* would be opened by the overload relay. The load would be automatically thrown over to the other line without interruption of service. This means that for a short time the second line and its transformers would possibly be overloaded, but in the worst case such an overload would not exceed 100 per cent and the apparatus should be capable of carrying such an overload for a period of time sufficient to open switches *K* and *M* and close switches *S* and *T*, after which transformer banks *II* and *I* can again be put into service in parallel with *V* and *W* on the second line.

The scheme of operation would be exactly the same if each of the four transformer banks shown were replaced by two or more banks, so long as they were paralleled on one high-tension line, under which conditions, in order to clear the line, it would be necessary to cut off all of the low-tension transformer switches involved. Usually it is not practicable to carry much over 20,000 kw. on a single transmission line, and a single bank of transformers can readily be used with a line of such capacity, that is, each single-phase transformer would be rated at say 6666 kw. Such a size would be economical for high-voltage design and the entire layout would be cheaper, as regards both transformers and switching equipment, than if a greater number of transformer banks were used.

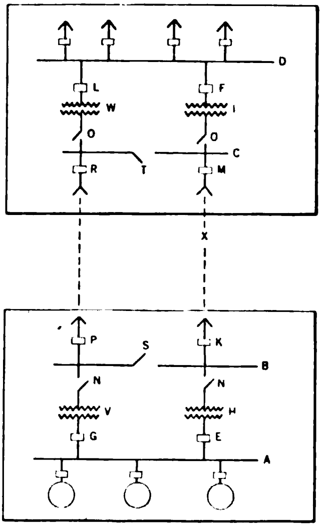


FIG. 1

This system permits, under ordinary conditions, all of the automatic switching to be done on the low-tension side, which in itself is an advantage. Some tests were made about two years ago on a large 44,000-volt system by putting spark gaps across individual coils of the high-potential winding of a transformer and setting up disturbances on the high-tension line. The voltages across the coils, indicated by the spark gaps, varied from something like three to four times normal in case of an arcing ground to about twenty times normal for operation of a high-tension switch. Such results merit careful consideration. Further, with the transformers grouped with relation to each line, instead of being paralleled on the high-tension bus, the effective reactance in circuit when a short circuit occurs in the high-tension line is so much higher that the rush of current is materially lessened, thus decreasing the danger of damage to line insulators by high-power arcs and of burning off line conductors. I believe that entirely aside from any question of the danger of high-tension switching, the advantages of such a system of connections merit its use simply from the standpoint of decreased first cost of transformers and switching equipment, and the reduction in destructive effects of line disturbances, due to the increased effective reactance.

In the past, some objection has been made to reverse energy relays, as it was claimed that under the potential drop due to short circuit they would fail to operate properly. This difficulty has been practically done away with in most of the reverse energy relays now on the market, and further, under the conditions which usually obtain, they will not operate on overloads. Only recently, in putting into service a 120,000-volt system, about 150 miles long, where the principles indicated above were carried out strictly, a short circuit was made on the high-tension side of one of the substation transformers. The reverse energy relay acted promptly, notwithstanding the drop produced by the short circuit. Several other occurrences took place causing line disturbances, such as a lightning stroke on the line close to the generating station, a short circuit produced by wire falling across transmission line, etc., but in each case the relays operated properly so as to cut out only the line in trouble, without interrupting service. The diagram, Fig. 1, shows only two simple stations. The same principles, however, can be applied to any number of stations and substations tied together in a system, provided there are two transmission circuits.

E. A. Lof: There is one point of particular interest in this report, and this is the section on pages 1463 and 1464 dealing with the operation of a system with one of the phase wires grounded. It is notable here that for systems of very high voltage the effect of such an operation has been rather severe. One company, for example, states that it has had numerous punctures of insulators and breakdowns of bushings, while another company states that the effects have been too severe to operate its system with one wire grounded.

This brings out an important point. For a Y-connected system with the neutral grounded, the grounding of one phase wire will short-circuit this particular phase and the circuit breakers will trip, thus entirely cutting out the line. For a non-grounded, delta-connected system, however, the grounding of one phase will have the effect of increasing the capacity of the line. Under normal operation this capacity is in proportion of the voltage to the neutral, but when one line becomes grounded this voltage is increased to the full line potential, and the charging current will be proportionately increased. This in turn raises the voltage at no-load, which will be about 70 per cent higher than it would be when under normal operation. Actual experience has proved that this is the case and it probably will be one of the most important factors which will decide against delta connection for systems of very high voltage.

Selby Haar (by letter): The report which is now laid before the Institute is a thorough piece of work, and one which fully entitles the committee to the special thanks of the members. It is regrettable, however, that approximately complete replies were obtained from less than one-fourth of the companies addressed.

The writer, having recently made a somewhat similar investigation (covering transmission systems all over the world, however), would like to call attention to certain practises brought out in the report by citing other solutions of the same problems. (The numbering of the following items refers to the list of questions given in the Appendix to the committee report).

A-2. The tower is seldom used abroad, metal poles being selected for high voltages, and wood or concrete for lower voltages.

B-1 to 15. The following data apply to a 70,000 -volt Swiss line recently built.

1. 19-strand cables 0.394 in. diameter, breaking strength 57,000 lb. per sq. in., $E = 17,700,000$ lb. per sq. in. (working stress 8500 lb. per sq. in.).
3. 7-strand cables 0.315 in. diameter, breaking strength 113,000 lb. per sq. in., $E = 31,500,000$ lb. per sq. in.
6. Wind pressure only, for ordinary poles.
7. 14.3 lb. per sq. ft.
8. −25 deg. cent.
9. + 40 deg. cent.; − 25 deg. cent.
10. Snow (not ice) 0.394 in. thick, weighing 10 lb. per cu. ft.
11. − 25 deg. cent.
12. 14.3 lb. per sq. ft.
13. Yes.
14. Every $\frac{2}{3}$ to 1 mi.
15. All wires on one side broken, and wind pressure of 20.4 lb. per sq. ft. adding directly to conductor pull.

B-23. This is not infrequently claimed.

C-24. In Europe, the high-tension neutral is usually not grounded, but the generator neutral is.

C-38. The transmission line of the Moutiers-Lyons direct-current system in France, the operating voltage of which has reached about 80,000 volts, includes about 2.5 miles of cable (out of 112).

D-1. Foreign operating companies use the same types of lightning arresters for all high tensions, namely, horn gaps with series resistance, reactance coils, and liquid static dischargers. Condensers are being tried in several places. There is also to be noted an attempt to proportion the whole transmission and switching system to minimize as far as possible the generation of excess voltages.

E-1. The opinion of several experienced American engineers is that an effective arc suppressor and a plain horn gap set rather high give protection which is "hard to beat."

For the benefit of members who have to examine certain features of transmission plants in great detail, a list of references, mostly to periodical literature, collected by the writer in his investigation (*Electrical World*, April 25, 1914, p. 925) is appended. In this list are descriptions, etc., of over fifty plants designed for 70,000 volts or above.

HIGH-VOLTAGE POWER TRANSMISSION SYSTEMS

Pacific Light and Power Co., 150,000 volts.
  Elec. Jl. 1913, p. 768.
  Elec. Rev. & West. Elecn. 3-1913, p. 583.
  Elec. Wld., 6-1912, p. 1200, 1342; 11-1913, p. 1108; 1-1914, p. 337, 385.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. News, 11-1913, p. 843.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Au Sable Electric Co., 140,000 volts.
  Elec. Wld., 4-1912, p. 795, 843; 6-1912, p. 1195.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. Mag., 4-1913, p. 53.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
  Lundquist, "Transmission Line Construction," p. 46.
Southern Sierras Power Co., 140,000 volts.
  El. Rev. & West. Elecn., 10-1912, p. 814.
  Elec. Wld., 8-1912, p. 298; 8-1913, p. 234.
  Elek. Zeit., 10-1913, p. 1242.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
  Jl. Elec., Pr., Gas 7-1913, p. 1, 33.
Utah Power & Light Co., 130,000 volts.
  Elec. Wld., 7-1913, p. 106.
  G. E. Rev., 1913, p. 359.
Pacific Gas & Electric Co., 125,000 volts.
  Elec. Wld., 11-1913, p. 1055.
  Eng. Rec., 11-1913, p. 573.
West Penn. Traction & Water Power Co., 125,000 volts.
  Elec. Rev., & West. Elecn. 11-1912, p. 990; 4-1913, p. 726.
  Elec. Wld., 6-1912, p. 1280.
  Iron Age, 11-1912, p. 1296.
Tennessee Power Co., 120,000 volts.
  Elec. Rev. & West. Elecn., 2-1913, p. 267.
  Elec. Wld., 4-1912, p. 820; 3-1913, p. 644,696; 5-1913, p. 1111; 10-1913, p. 868.
  Power, 3-1914, p. 360.

Connecticut River Transmission Co., 120,000 volts.
 Elec. Wld., 10-1913, p. 685; 3-1914, p. 565.
Inawashiro Hydroelectric Power Co., 115,000 volts.
 Elec. Wld., 3-1912, p. 524; 5-1913, p. 1058.
Engg. London, 10-1913, p. 35.
 Z. V. d. I., 4-1912, p. 569.
Au Sable Electric Co., 110,000 volts.
 Elec. Wld., 11-1906, p. 841; 11-1907, p. 850; 2-1909, p. 354; 9-1909, p. 664; 6-1912, p. 1195.
 Elek. Zeit., 10-1913, p. 1242.
 Eng. Mag., 4-1913, p. 53.
 Eng. Rec., 10-1907, p. 418, 462.
 G. E. Rev., 1909, p. 86.
Hydroelectric Power Commission of Ontario, 110,000 volts.
 Elec. Wld., 1-1912, p. 33, 96, 137; 6-1912, p. 1195.
 Elecn., London, 3-1912, p. 912.
 Elek. Kr. & B., 1909, p. 337; 1910, p. 526, 727.
 Elek. Zeit., 10-1913, p. 1242.
 Eng. Mag., 4-1913, p. 53.
 G. E. Rev., 1912, p. 336; 1913, p. 352.
 Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
 TRANS., A. I. E. E., 24-1905, p. 807.
 Lundquist, " Transmission Line Construction," p. 45.
Lauchhammer, A. G., 110,000 volts.
 Elec. Wld., 10-1911, p. 1057; 6-1912, p. 1195.
 Elek. Zeit., 1911, several places; 10-1913, p. 1242.
 Lundquist, " Transmission Line Construction," p. 96, 97.
Georgia Railway & Power Co., 110,000 volts.
 Elec. Rev. & West. Elecn., 2-1913, p. 267.
 Elec. Wld., 5-1911, p. 1127; 6-1912, p. 1195; 12-1913, p. 1257, 1309.
 Elek. Zeit., 10-1913, p. 1242.
 Eng. Mag., 4-1913, p. 53.
 Eng. News, 1-1914, p. 240.
 G. E. Rev., 1912, p. 336; 1913, p. 352; 1914, p. 608.
 Alabama Power Co., 110,000 volts.
 Elec. Wld., 3-1912, p. 610; 1-1913, p. 68; 6-1913, p. 1278; 9-1913, p.527
 G. E. Rev., 1913, p. 386.
Mississippi River Power Co., 110,000 volts.
 Elec. Wld., 4-1913, p. 715; 5-1913, p. 1157.
 Elek. Zeit., 10-1913, p. 1231, 1242.
 Eng. Mag., 4-1913, p. 53.
 G. E. Rev., 1912, p. 336; 1913, p. 352; 1914, p. 85, 375.
 Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lehigh Navigation Electric Co., 110,000 volts.
 Elec. Wld., 4-1913, p. 902; 5-1914, p. 1035, 1093.
Cedar Rapids Manufacturing & Power Co., 110,000 volts.
 Elec. Wld., 4-1913, p. 902; 7-1913, p. 105; 8 -1913. p. 319.
 Eng. Rec., 10-1913, p. 461.
 G. E. Rev., 1913, p. 336.
Mexican Northern Power Co., 110,000 volts.
 Elec. Wld., 5-1913, p. 1190; 7-1913, p. 155.

G. E. Rev., 1912, p. 336.
Ebro Irrigation & Power Co., Ltd., 110,000 volts.
Elec. Wld., 1-1913, p. 212.
Chile Exploration Co., 110,000 volts.
Elec. Wld., 5-1913, p. 1191.
Eng. & Min. Jl., 1-1914, p. 63.
Sierra & San Francisco Power Co., 104,000 volts.
Elec. Wld., 6-1912, p. 1193; 9-1908, p. 667; 10-1908, p. 946.
Elek, Kr. & B., 1910, p. 160.
Eng. Mag., 4-1913, p. 53.
Eng. News, 5-1909, p. 516.
G. E. Rev., 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lundquist, " Transmission Line Construction," p. 45.
Great Falls Power Co., 102,000 volts.
Bull. A. I. M. E., 8-1913, p. 1907.
Elec. Wld., 6-1912, p. 1195.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1911, p. 149, 207; 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
TRANS. A. I. E. E., 1911, p. 2002.
Yadkin River Power Co., 100,000 volts.
Elec. Wld., 3-1911, p. 748; 4-1911, p. 799; 5-1911, p. 1128; 8-1911, p. 261, 4-1912, p. 774.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1912, p. 336.
Colorado Power Co., 100,000 volts.
Elec. Wld., 1-1910, p. 217, 6-1910, p. 1649; 6-1912, p. 1195, 1205.
Elek. Zeit., 10-1913, p. 1242.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lundquist, " Transmission Line Construction," p. 47.
Taylor, " Transformer Practise," p. 270.
Great Western Power Co., 100,000 volts.
Elec. Rev. & West. Elecn, 2-1913, p. 267.
Elec. Wld., 8-1909, p. 471; 9-1909, p. 657, 712; 6-1912, p. 1193, 1195; 6-1913, p. 1277.
Elek. Kr. & B., 1910, p. 160.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 3-1910, p. 851, (vol. 38).
Eng. News, 5-1909, p. 516.
G. E. Rev., 1911, p. 6, 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
TRANS. A. I. E. E., 1911, p. 1994.
Taylor, " Transformer Practise," p. 270.
Southern Power Co., 100,000 volts.
Elec. Jl., 1911, p. 329.
Elec. Wld., 12-1907, p. 1241; 3-1910, p. 741; 7-1911; p. 17; 6-1912, p. 1195.

Elek. Kr. & B., 1911, p. 175.
Elek. Zeit., 10-1913, p. 1242.
G. E. Rev., 1909, p. 551; 1910, p. 24; 1912, p. 336; 1913, p. 352.
Eng. Mag. 4-1913, p. 53.
TRANS. A. I. E. E., 1908, p. 819; 1911, p. 1998.
Lundquist, " Transmission Line Construction," p. 48.

Shawinigan Water & Power Co., 100,000 volts.
Elec. Wld., 5-1912, p. 953, 1015; 6-1912, p. 1195
Elek. Zeit., 10-1913, p. 1242.
G. E. Rev., 1913, p. 352.

Los Angeles Aqueduct, 100,000 volts.
Elec. Wld., 1-1912, p. 30; 5-1913, p. 955.
Eng. Rec., 8-1913, p. 476.

Tata Hydroelectric Co., 100,000 volts.
Elec. Wld., 6-1913, p. 1332; 11-1913, p. 950.
Engr., London, 4-1911, p. 402.
Engg., London, 10-1913, p. 547, 578.
Eng. Rec., 11-1913, p.

Societa Italiana di Elettrochimica, 88,000 volts.
D'Elettricita, 12-1913, p. 72.
Elec. Rev., Lond., 11-1910, p. 832; 12-1910, p 913.
Elec. Wld., 9-1910, p. 741.
Elecn., Lond., 4-1910, p. 67.
La Rev. Elec., 8-1910, p. 119.

Appalachian Power Co., 88,000 volts.
Elec. Wld., 11-1912, p. 1141.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1912, p. 336; 1913, p. 352.
Taylor, " Transformer Practise," p. 270.

Rio Janeiro Tramway Light & Power Co., Ltd., 88,000 volts.
Elec. Wld., 5-1909, p. 1153; 8-1909, p. 367; 4-1913, p. 897.
Elecn., Lond., 8-1911, p. 694.
Elek. Kr. & B., 1910, p. 584; 1911, p. 175.

Tasmania Hydroelectric & Metal Co., 88,000 volts.
Australian Mining Standard, 3-1911, p. 296.
Elec. Wld., 4-1912, p. 820.
Engg., Lond., 11-1910, p. 709.
Garcke, " Manual of Electrical Undertakings," vol. 17, p. 1437.

Mexican Light & Power Co., 85,000 volts.
G. E. Rev., 1912, p. 336.
Trans. A. S. C. E., vol. 58, 1907, p. 37.
Taylor, " Transformer Practise," p. 270.

Toronto Power Co., 85,000 volts.
Elec. Rev. & West. Elecn., 7-1906, p. 138.
Eng. Mag., 3-1910, p. 855.
Trans. A. S. C. E., vol. 65, 1909, p. 181.
Lundquist " Transmission Line Construction," p. 43.
Taylor, " Transformer Practise," p. 270.

Victoria Falls & Transvaal Power Co., 84,000 volts.
Jl. (British) I. E. E., vol 51. 6-1913, p. 2.

See also EWE: 46: 1117 June 30, 1905 for proposed 700-mile transmission

Trans. So. Afr. I. E. E., 1913, p. 170.
Klingenberg, " Baugrosser Elektrizitaetswerke," p. 177.
Energia Electrica de Cataluna, 80,000 volts.
Engr., Lond., 10-1912, p. 384.
Z. V. d. I., 11-1912, p. 1791.
Swedish State Railways, 80,000 volts single-phase.
Elek. Kr. & B., 11-1913, p. 658; 3-1914, p. 161.
Katsuragawa Denryoku Kabushiki Kaisha, 77,000 volts.
G. E. Rev., 1912, p. 336.
Southern California Edison Co., 75,000 volts.
Elec. Wld., 8-1907, p. 277, 317, 359, 401; 10-1909, p. 1039; 6-1912, p. 1190, 1195.
Au Sable Electric Co., 72,000 volts.
Elec. Wld., 11-1906, p. 841, 9-1907, p. 528.
Elek. Zeit., 1909, p. 478.
Societa Generale Elettrica dell'Adamello, 72,000 volts.
Elecn., Lond., 7-1912, p. 608, 649.
Engr., Lond., 9-1912, p. 293, 319, 349, 373, 401.
Eng. News., 12-1911, p. 764.
Montana Company, 70,000 volts.
Bull. A. I. E. M. E., 8-1913, p. 1907.
Elec. Wld., 7-1901, p. 53; 5-1908, p. 1088; 8-1910, p. 432.
Elek. Kr. & B., 1911, p. 175.
Eng. News, 10-1910, p. 430.
Trans. A. S. C. E., vol. 50, 1903, p. 212.
Taylor, " Transformer Practise," p. 270.
Hidroelectrica Espanola Molinar, 70,000 volts.
Elek. Zeit., 1911, p. 535, 561, 586, 766.
Pennsylvania Water & Power Co., 70,000 volts
Elec. Wld., 10-1910, p. 929; 5-1911, p. 1125; 8-1912, p. 395; 11-1913, p. 924; 2-1914, p. 314.
Eng. Mag., 3-1910, p. 855; 4-1913, p. 53.
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DISCUSSION ON "SPECIFICATION FOR INSULATOR TESTING—COVERING INSPECTION AND TESTS OF HIGH-TENSION LINE INSULATORS OF PORCELAIN, FOR OVER 25,000 VOLTS" (ENGINEERING DATA SUB-COMMITTEE), DETROIT, MICH., JUNE 25, 1914. (SEE PROCEEDINGS FOR OCTOBER, 1914.)

(Subject to final revision for the Transactions.)

Percy H. Thomas: Last year, the High-Tension Transmission Committee presented a "sample" or "model" or "skeleton" specification, as it might be called, for the testing and inspection of high-tension porcelain insulators. This has been quite extensively remodeled during the present year, without greatly changing the fundamental ideas of the specifications. Presumably this discussion will be the last chance for any effective criticism. I wish to open the subject by giving a few words of explanation in answer to a number of the suggestions which have been made.

I will call attention first to the fact that the high-tension insulator industry has developed under existing conditions, until at the present time it has reached large proportions. These insulators are all tested and used according to certain customary methods which are now well understood and generally accepted. It is not practicable for the Institute to step in and pass a resolution saying that hereafter the industry shall change about and follow some specification which it would present, radically different from the former practise. If our specification is to be used at all, it must be close enough to present methods, so that it can be followed without upsetting the general practise of the industry. This is our first limitation.

The second limitation is the fact that the manufacturers of insulators have their own electrical testing apparatus and mechanical testing apparatus, and it is only a very small percentage of the insulators actually manufactured and used that are tested on any other apparatus. We now have in addition two or three laboratories, outside of the electrical manufacturing companies, where tests can be made, but they are not accessible to a very large number of the users of insulators, and our specification must be so drawn that it will fit into the particular installations of testing apparatus at the manufacturers' plants.

Another thing which limits the extent of change that may be embodied in the proposed specification is the fact that the tests which the purchaser usually makes on his insulators are an integral part of the manufacturing process of the manufacturing companies. The manufacturing companies rely on this inspection and test, to a large extent, to check up and eliminate and weed out the bad material from their product. We should draw our specification in such a way that this will continue to be the fact.

I will repeat, what perhaps you have forgotten, that the backbone of this specification was originally drawn by the engineers of one of the insulator companies. Mr. Peek also gave us a model specification. Most of the meat of Mr. Peek's specification was put over into the manufacturer's specification.

Perhaps the greatest value of this testing specification is the stating in definite form for the *average* engineer those particular facts, those broad methods, those general characteristics, which the most experienced engineers have found to be the most helpful in selecting and testing insulators. There is a good deal of educational matter in the specification that has been seriously objected to by a number of those who have favored us with criticisms, and I can understand their point of view—it goes against their sense of proper form for a specification on which materials are to be bought to include explanatory sentences and general statements, but, looking at the matter from a broad point of view and considering the practical results to be obtained, it seems to me these educational interpolations are a very important part of the whole.

There is great objection on the part of some to the use of the words "design test" to describe those tests which are made on a few insulators to determine the characteristics of the type, as distinguished from the routine tests made on every insulator. From a certain point of view the design should, as the critics claim, be determined before the test specification is adopted. However, the actual tests given in the specification as design tests should be made as called for in most cases, so that it reduces to a question of terms, and the term used is frequently used and I know of none better.

One of the suggestions that comes most frequently is that we specify the minimum size of transformer capacity that is safe for testing insulators. The necessity of using large-capacity transformers occurs only when comparative tests are to be made on different transformers or where for some other reason sine wave form is important. Ordinarily for routine tests it is desirable to limit the capacity of the testing transformer to prevent arcs on the insulators. The manufacturers of insulators have transformers of limited capacity installed, some of them of peculiar design from the point of view of power transformer design, and most of them use some means of limiting the capacity, either series resistance or series choke coils, or weakening the field of the generator.

Some one asked for a specification as to the quality of oil in which to make the oil puncture test, but I hardly think that is necessary. There is no trouble to get the insulator to puncture under oil, rather than flash over, and I cannot imagine that the quality of the oil would make much difference in the puncture quality of the porcelain.

I would call attention to the so-called combined electrical and mechanical test in the appendix. This test calls for the application of mechanical strain while the electrical potential is on. You will remember last year at Cooperstown Mr. Nicholson gave us some data showing that certain insulators punctured with less than half their normal puncture value when mechanical strains of less than half the ultimate strength were impressed upon them. The year past has shown an investigation of this matter and a very great improvement. The test is easily applied. One manufacturer has a wooden arm testing frame, and puts voltage on a single insulator, allowing it to flash over, or he applies the voltage just below the flash-over, as may be desired, and gradually brings up the mechanical pressure until the insulator punctures.

E. E. F. Creighton: During the last three years we have given considerable attention to this matter of testing insulators, and I wish to take it up from a different point of view from that of the committee. I think the specifications are very desirable in the form in which they are now presented—they are made, however, from the point of view of the man buying insulators, and I shall take the point of view of the man using insulators.

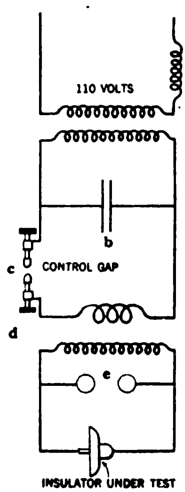


Fig. 1

Mr. Thomas has pointed out the difficulty that a user has in getting testing apparatus with which to test the insulators, the cost of it, and the details involved in carrying out the work. It was about one and one-half years ago, when a paper was presented on this subject in New York, that I had a very brief opportunity to show the oscillation transformer as a method of testing insulators, but the method has not been followed up in the proceedings of the committee—perhaps they lack definite information on the subject. I wish to give some instances of the use of this method, and point out some of its advantages. We started out with a problem such as many have at the present time—namely, the frequent loss of installed insulators. Forty of these insulators were removed from a line and taken to the laboratory, and there was applied to them a 60-cycle test, and four insulators punctured under this test at the flash-over potential. The 36 insulators left were then tested out with a high-frequency transformer and all failed. The diagram, Fig. 1, shows the well-known connections of an oscillating transformer set. The first circuit, at 110 volts, say, is stepped up to any convenient voltage, which I shall designate as 13 kv., which charges a condenser. The condenser sparks through an adjustable gap and coreless transformer. The coreless transformer gives a high potential at a high oscillating frequency. The insulator to be tested is connected across the high-voltage side of this transformer. The potential applied to the insulator is gradually increased by starting with the control gap very small and gradually screwing it open. By opening this gap carefully, any potential desired may be applied to the insulator at a frequency of several hundred thousand cycles per second, a convenient value being in the neighborhood of 200,000 cycles. The natural make-up of these transformers will give from 100,000 to 300,000 cycles. There is little need at present to question the proper value of this frequency, whether 100,000 or 200,000 cycles is to be used, because there has been such a tremendous step in going from 60 cycles to 200,000 cycles that an increase to 300,000 cycles is comparatively negligible in its effects. The higher the frequency the more the corona sparks follow the surface of the porcelain.

With apparatus of this kind we have made a great many tests in the porcelain factory itself, also the tests of insulators taken from lines and of insulators fresh from the manufacturers. In the early work it was feared that the test was too severe, and it was, since we did not take precautions at that time to bring up the voltage gradually by opening the control gap. It soon became evident that the voltage must be held under control and the adjustable control gap was therefore made an intrinsic part of the apparatus. An illustration of the value of the method is given by a series of tests which were applied to wet process porcelain bushings. Lots of one hundred bushings, as they came from the kilns, were tested on 60 cycles, bringing the potential up until it sparked over, then holding the potential a little below that value for one minute, and out of the one hundred there would be, as there always are, a few defective ones. They were then tested out on the high-frequency circuit. Going through different types of insulators, and insulators from different firings, there was a percentage of from zero to 17 per cent additional loss.

Another group of insulators was then taken, one hundred in a group, and tested on the high-frequency circuit first, and the defective insulators were removed as fast as they showed up. The insulators that were left after this high-frequency test were passed through a 60-cycle test; and although many hundreds of insulators were treated in that way, there was never a single case where an insulator which passed the high-frequency test was in any way damaged on the 60-cycle test. That, in itself, is proof sufficient that the high-frequency test is better than the 60-cycle test.

The next question arises—is it a fair test? At the present moment I am not going to discuss that, but simply say that the test can be made as reasonable or as severe as desired by the simple adjustment of the control gap. By opening the control gap to its widest value, super-spark potential may, of course, be thrown on the insulator and damage may result. For example, if the sparking potential of the insulator is 80,000 volts, it is easy enough to arrange the gap so as to throw on the insulator at the first instant a voltage of 175,000 volts. That value of voltage exists on the insulator during only the brief time necessary for the arc to creep around the surface from cap to pin. Such a severe test is not to be recommended as a standard test.

Testing just at and below the spark potential is both desirable and fair to porcelain of good design and material. This seems sufficient comment on the severity of test.

Every line at the present time has insulators on it that are old—perhaps only a dozen years old, but that is very old in the art of making insulators. At that time insulators were made very much like dinner plates, and very little attention was paid to the subsequent testing. I find that old insulators taken from a number of different systems are very liable to be in a condition that is sometimes designated as porous, due to underfiring. These insulators are necessarily weak electrically. The problem, then, of the operating engineers is not only how to buy good new insulators, but what to do with the old ones. It is usually impracticable to take down from the pole line all of the insulators and stand the loss which comes from mechanical accidents in handling and shipment to a laboratory to have tests made. Therefore, it is necessary for the engineers of a transmission company to be able to make tests, and not only make them themselves, but if desirable to make them on the insulators in place on the line. The oscillator form of testing, then, gives the possibility of having universally available a light, cheap and effective means of testing insulators, either new from the factory, or old, in service.

The question of kilowatt capacity for testing has been brought up by Mr. Thomas. In the oscillator sets the kilowatt capacity of the 60-cycle transformers is extremely small—1, 2 or 3 kilowatts—even a potential transformer has been used, although it cannot be used continuously, due to the overload. A very small kilowatt capacity in the 60-cycle circuit will sound unreasonable to those who contend that it is absolutely necessary to have a large generator and a large transformer in order to get reasonable results in testing, but that is not true in this case, for the actual power of this outfit, even with a small transformer, is considerably greater than any of the 60-cycle testing outfits that are in common use at the present time, without exception. The difference comes in this, that the energy is taken by the condenser at comparatively low power during a quarter-cycle of the generator wave. Although this period of time is of the order of 0.01 second, it is an extremely long time as compared to the time of discharge of the condenser. When the potential has risen to the maximum point of the 60-cycle wave, it breaks over the control gap. The full charge of the condenser will be given out at a rate which will depend upon the capacitance and the inductance of the oscillating circuit. As a matter of fact, the condenser is capable of giving out several thousand kilovolt-amperes for an instant, so there is no question about a sufficient kilowatt capacity.

In conclusion I wish to say one word in regard to one of the suggestions presented in the specifications, about uniformity—the valuable recommendation is that if a certain percentage of the insulators fail the entire lot should be rejected. This ruling can be more efficiently applied if the insulators can be divided into lots corresponding to definite zones in a kiln and to definite firings.

Percy H. Thomas: How do you determine the voltage and the frequency on the high side of the oscillation transformer?

E. E. F. Creighton: The frequency is measured either directly by cymometer or calculated, and the calculations agree so accurately with the measurements that the easiest method is by calculation. The cymometer is an instrument as easy to handle as a wattmeter. Once the method of use is learned it is easy to handle. In the matter of potential there is some question; there is no way today of accurately measuring high-frequency potential. The potential as given by the proposed standard sphere gap is assumed to be correct. The limitation designated by Mr. Peek is to make the length of gap not greater than three times the radius. That is the only basis we have for the direct measurement of high-frequency voltage. Practically it is simply a matter of what equivalent gap will spoil an insulator. The spark potentials at arc-over voltage for 60 cycles and 200,000 cycles agree closely, in general.

Percy H. Thomas: There is no question that this method Professor Creighton has been telling us about, and which he fully described and demonstrated at the December, 1912, meeting in New York, is a powerful instrument of research, but I doubt if he would consider that it is quite definitely enough established to embody in the specification.

E. E. F. Creighton: This is as definite a test as some which have been put in the specification. I refer to the impulse test. The impulse test has been made a part of the appendix, and this test which I have shown is far better understood and can be made less dangerous than the impulse test.

Percy H. Thomas: That leads to a point I want to bring out, as to the relative characteristics of the test Professor Creighton has described and the impact test called for in the specification. The difference is this—the impact test of the specification is a shock test, a feeble shock, applied to the insulator, almost exactly paralleling the condition of service brought about by lightning and switching. It shows, if properly carried out, no element of heating. This test referred to by Professor Creighton, is, if I am not mistaken, entirely dominated by the heating effect produced by the high-frequency current; what I mean to say is this—when we have a high potential impressed on any insulator, the material of the porcelain is subject to an extreme pressure. Every time that test is reversed, a new element of heat is added. With the 300,000 cycles, you have 300 times the amount of heat generated, due to the expansion of material, that you do in the single shock. The net result is not only the heating of the insulator, but the heating of the air in the particular place where the interruption of potential is greatest. I do not think you realize how quickly the dielectric strength of porcelain goes down as the temperature goes up. I cannot give definite figures. Two or three times the boiling point of water is enough to make a great difference in the insulation resistance of porcelain. It is the extent and degree of the heating of the dielectric material at that high frequency which is, it seems to me, the thing we must know more about before we can use this test. In actual service we do not get that condition—we get two or three impacts, but never sustained high frequency. It is putting a great premium on efficiency in a thing which, while it may be indirectly related to the serviceability of the insulator, is not necessarily related to it.

E. E. F. Creighton: I feel that this criticism is unjust, because it cannot be shown where the heating comes in. We can take an insulator of this kind and place it under the oscillation test for a whole minute, and all the time the spark discharges are streaming over the porcelain surface. It looks hot while the sparks are playing, but no appreciable rise in temperature is noticed after such a test by placing the hand on the surface. There is no doubt that a continuous strain applied at one point will heat the insulator. If one of these insulators is subjected to the continued voltage of an Alexanderson generator it is possible to make it red hot, but the application of the oscillator is different. There is a relatively long interval of rest between successive applications of high-frequency trains. The high potential is applied for a very small fraction of the total time. Judging from the many hundreds of tests we have made, I feel that the heating of the insulator, except in air spots where it is weak and where it ought to be heated, is entirely a negligible quantity.

Edward Bennett: I want to endorse most heartily what Mr. Creighton has said about the desirability of using impulse test circuits having such constants that fairly definite ideas can be formed of the rate at which the voltage across the insulator rises, and of the frequency of the applied stress across the insulator, provided the insulator under test does not flash over during the first half-cycle of the high-frequency oscillation.

The objection to the type of impulse circuit shown in Fig. 1 of the specification is that from the dimensions of such a circuit one can not determine very accurately the rate at which the potential rises across the insulator. This uncertainty arises from the fact that in the circuit shown in Fig. 1 in the specification, even when used with fixed inductance, capacity and setting of the gap A, the rate at which the voltage rises across the insulator will depend upon the variable capacity of the different types of insulators under test. Suppose, however, that the type of circuit which Mr. Creighton has suggested is slightly modified by connecting across the secondary of the oscillation transformer, and in parallel with the insulator under test, a condenser having a capacity five or six times that of the insulator, as shown in Fig. 2 herewith. From the setting of the gap and the dimensions of such a circuit, one may compute with a satisfactory degree of accuracy the manner in which the potential will rise across the insulator up to the instant at which breakdown or flash-over occurs.

A slight modification of the simple series circuit of Fig. 1· of the specification would eliminate the uncertainty due to the variable and unknown capacity of the different types of insulators under test, and would seem to render this circuit more satisfactory than the oscillation transformer connections advocated by Mr. Creighton. The modification of Fig. 1 of the specification is shown in Fig. 2. It consists in connecting the insulator under test in parallel with another plate condenser having a capacity about five times that of the insulator. The capacity of the 12 in. by 12 in. triple-petticoat insulators used on 40-kv. lines is about 2×10^{-11} farads from line wire to pin, and the capacity of a 10-in. single-piece suspension unit is about 3×10^{-11} farads from metal to metal. That is, the combined capacity of the condenser *B* and the insulator ought to be about 10^{-10} farads or approximately the same as the condenser *C*.

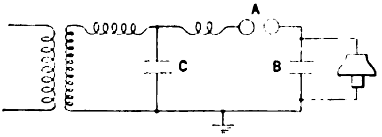


FIG. 2

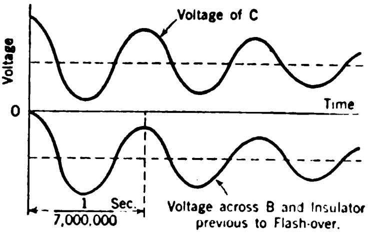


FIG. 3

If the coil *L* and the leads consist of about 30 ft. (900 cm.) of heavy copper, the inductance of the oscillatory circuit may be estimated at 0.01 millihenry. Such a circuit up to the instant of failure of the insulator will have a frequency of oscillation of approximately 7,000,000 cycles per second and the relation between the condenser voltages and time up to the instant of insulator breakdown will be as illustrated in Fig. 3. It is to be noted that the insulator, if it does not flash over during the first half-cycle, will be subject to a unidirectional pulsating voltage and not to an alternating voltage.

E. M. Hewlett: I would like to hear some discussion on the subject of the absorption test. Could not something in the nature of a year's guarantee be required? I have found insulators to fail from imperfect vitrification, which had passed all the different kinds of tests. Some of them fail in the course of a year, or six months, even, showing they have not been thoroughly vitrified, and still, to begin with, they will stand all the different tests. Until there is a test which will show definitely whether an insulator has been throughly vitrified, it would seem as though the insulator should come under the same kind of guarantee as a piece of machinery, as they are very often used in connection with the switching devices, to support busbars, etc., and should be considered as machines in that case.

Farley Osgood: In our somewhat extended system of multiple operation of transmission lines, fed by large-capacity generating stations operating in parallel, we learned from our charted data on service interruptions that the chief initial cause was the insulator. All testing at normal pressure (13,000 volts) brought us no real knowledge of our difficulty, so testing apparatus for more than three times normal voltage (40,000 volts) with 1000-kw. capacity was installed. Tests with this taught us no more than we could learn with line voltage testing, so we had made a testing outfit which, by means of a Tesla coil and condensers, gave us a frequency approximating 250,000 cycles.

We brought in from our lines samples of all types of insulators in service, fifteen types in all, several of which were designed for operating at three times the voltage on which they were being used, and all but two types failed under our test, meaning that the insulator would puncture before it would arc over, and the two types which showed reasonable results were not the insulators designed for higher voltage than the service in which they were placed.

Our high-voltage, large-capacity transformer would not develop this information, and only with the high-frequency testing outfit could we get the results which taught us that our insulators were wrong in design, in spite of the fact that they were the types specified by the manufacturers for the service, and met all the manufacturer's test guarantees.

The result of our work has been a new standard insulator for our 13,000-volt service which is about the same size as our original insulator but has thicker petticoats and which will spill over before it will puncture.

An analysis of our difficulties showed that unquestionably our troubles were caused by the effect of switching, which takes place frequently in a large system with big stations in parallel, and which effects were from high frequencies, and therefore we feel that the high-frequency test is the most useful one of all. It is the test which tells the operating man what he wants to know, and should be made in addition to any other tests that a manufacturer thinks necessary to establish the mechanical perfection of his product, as the high-frequency test is really one on the design of the insulator, rather than its structure.

We now give every insulator a high-frequency test before it is placed in service, and a recent test of 13,127 pin type insulators showed a failure of 1.75 per cent, and of 2260 disk type 3.94 per cent of failure. While at first this may seem high, it is not really so, as the actual value of the insulators destroyed is small, and well worth while for the insurance of continuity of service.

The test is not expensive, is safe, and a crew of four men from the line department, with one laboratory man to handle the test set and keep the records, can unpack, test, and repack 1200 insulators in an eight-hour day.

The high-frequency test, using the Tesla coils, we believe presents the following advantages:

1. An even distribution of corona over the entire surface of the insulator, searching out imperfections.
2. Failures under test are absolutely definite, being readily recognized by
   (a) cessation of corona,
   (b) abrupt change of tone of spark due to shortened path,
   (c) steady discharge through point of failure.
3. The test does not require skilled labor, but can be conducted by anyone, after a little training, if his sight and hearing are normal.

We believe we have at last an equipment which can be made portable for use in the field in testing individual insulators in service without removing them from the line, the transmission voltage, of course, being removed, and we advise operating engineers to learn of the benefits to the service to be derived from such testing, by themselves, in addition to any test, or any guarantee, of any manufacturer, no matter what the type or line voltage of the insulator.

S. C. Lindsay: I want to take exception to what Mr. Thomas said about the impulse test being usually sufficient for insulators tested with high frequency. That test is not sufficient on delta-connected lines having no ground. Two disturbances occurred within the past year on the system with which I am connected, where arcing grounds lasted for two or three minutes, and a number of insulators was punctured each time. I should think it would be well to retain the high-frequency test so that insulators will meet these conditions.

Percy H. Thomas: They might get some sustained effect from the arcing ground—I do not know just how that would work out.

John B. Fisken: It occurred to me that I might give some information bearing on the subject of the rain test. I had occasion once to demonstrate that there was no danger to a person holding the nozzle of a fire hose, the stream from which was striking a line operating at 60,000 volts. While I was demonstrating that, I went a little further and tried to break down some of the insulators by spraying the stream on them. I hit every part of the insulators I could reach with that stream, and there was not the slightest sign of any breakdown. That satisfied me that a rain test was entirely unnecessary.

F. W. Peek, Jr.: Considerable has been said about "high frequency" testing and the effects of "high frequency" on insulators and insulation. Under this term are included without discrimination, continuous high frequency as from a generator, trains of oscillations from a Tesla coil, single impulses of exceedingly steep wave front as from lightning, etc. The effects of these are entirely different. As the results of tests are all attributed to the same cause, " high frequency," there is naturally much confusion.

As an illustration, take an ordinary single suspension insulator unit with an arc-over voltage of 90 kv. and a puncture voltage of 120 kv. (under oil) at 60 cycles. If a continuous high frequency at 10 kv. and 100,000 cycles is applied from an alternator, the insulator will soon become hot because of dielectric loss, and crack. The destruction of this insulator is due purely to heating. If trains of high-frequency oscillations at the rate of about 100 trains per second are applied, arcs will play over the surface of the insulator if the voltage is sufficiently high. To cause the unit just to arc over, a voltage somewhere between 90 and 130 kv. (higher than 60-cycle arc-over) will be required. A sufficiently long application will cause the insulator to break down. An oscillatory voltage of say 200 kv. may be applied. The discharge over the surface will be heavier. Breakdown will occur in a very short time, due to over-voltage. This voltage is higher than the 60-cycle puncture voltage. Although this unit arcs over, it takes a finite but very small time for the air to break down and the arc to occur as each wave train starts. The time is too small for the porcelain to break down on one wave train. It is injured, however, and the effect is accumulative. A sufficient number of trains causes breakdown. If an impulse of very steep wave front, of say 500 kv., is applied, arc-over occurs along the surface. Perhaps ten such impulses may be applied without apparent damage. At the eleventh impulse breakdown occurs. Each impulse has caused damage during this very short time that it takes the arc to occur. A needle gap set at 150 kv. across the insulation to " limit " the voltage will not prevent ultimate breakdown. The various and apparently inconsistent effects due to " high frequency " are thus not altogether mysterious.

Such tests are extremely valuable as design tests, uniformity tests, etc., but great caution is necessary and a thorough understanding of what sort of " high frequency " it is, when these tests are applied to insulators that are later to be used on lines, as the first lightning stroke may be in effect the ninth or even the eleventh impulse noted above.

Many failures undoubtedly do occur, due to "high frequency," but there is at present too much of a tendency to use this explanation when the real cause is quite simple, perhaps only a mechanical one. A great many insulator failures, perhaps most of them, are *fundamentally* caused by mechanical cracking gradually taking place, due to poor mechanical design, internal strains, etc., or absorbed moisture. Naturally, failure occurs on these *weakened* units during a voltage rise, as by lightning impulse. Of course there are also some failures due to the accumulated effects of over-voltage impulses on good units.

I believe that most moderate-voltage lines, 20 to 60 kv., are under-insulated. These lines extend out into open country and are subjected to the same lightning voltages as the very high voltage lines. The insulators have the same factor of safety as the high-voltage lines, but in terms of operating voltage. This naturally is without meaning, as, assuming good insulators at the start, destruction is not caused by line voltage but by lightning. I have illustrated this further with a definite example in a discussion at the Pittsfield meeting, May 29, 1914.

Farley Osgood: We believe that an insulator should spill over before it punctures, giving the line the accompanying relief from the strains of switching changes which are constantly taking place; and an insulator of this type will act as an arrester on the line, as it were. The operating man wants his system to come back intact after severe strains, and much prefers the chance of a momentary interruption of service to the almost certain discomfort of the shake-up resulting from complete insulator failures.

Therefore, in this belief we feel that the high-frequency test is the only one which will assure the operating man that the insulator will perform as desired in this relation of spill-over to puncture.

We have proved that much can be learned from this test, that field work with such a testing outfit will anticipate many failures, and we have proved that it is cheap, and that it is safe.

In spite of all the theories to the contrary, such as we have just heard, I feel that the operating man has at last come into his own, in the matter of finding out some things about his insulators for himself, and doing it right at home, and I hope that the practicability of the results of these simple and easily made tests will be appreciated.

William B. Jackson: I want to ask a question relating to this matter, and that is where the matter now stands, according to the researches and studies of the committee, in developing some suitable method of obtaining the capacity of the insulator, in the matter of mechanical shock, which has always seemed to be a rather important factor, although it has not been given very much consideration in tests.

Another question, which I presume has been studied by the committee, is whether there is any way by which the atmospheric effects may be accelerated in the passage of time upon the insulators. Guaranteeing an insulator for a year would be very small satisfaction, since insulators will run perfectly for two, three or as much as five years, and then break down.

Percy H. Thomas: The power of an insulator to hold a sustained load is now covered by a test in the specification, but I do not know any one who has proposed a test such as you indicate, and I do not know of any test that could be quantitatively expressed, so that an insulator would pass at 105 per cent and would not at 95 per cent. I do not know of any way by which we could approximate the effect of the weather. I wish we knew more of the effect of alkali dust, salt spray and condensation in connection with the rapid changes of temperature. These things are important, but we do not know the manner in which to produce such conditions beforehand.

William B. Jackson: They would be fruitful fields of study. In the case of cement, for instance, we have an impact test; in the case of concrete and cement, we have an acceleration test which is very valuable in the case of a building under construction. It seems that a study of that particular phase of insulators may bring good results.

Percy H. Thomas: The effect of electrical impact can be tested, but, mechanically, it is difficult to tell how the insulator will be affected.

DISCUSSION ON "REPORT BY THE JOINT COMMITTEE ON INDUCTIVE INTERFERENCE", SPOKANE, WASH., SEPTEMBER 11, 1914. (SEE PROCEEDINGS FOR SEPTEMBER, 1914.)

(Subject to final revision for the Transactions.)

P. N. Nunn: The paper just presented is one of signal interest and significance. It is of unusual moment in this, that it reports both an elaborate scientific study of great technical value and also a legal adjudication of conflicting interests between two public utilities of vast economic importance.

Briefly stated, the paper reproduces a certain report to the Railway Commission of the State of California, by a committee authorized by it to investigate the subject of electrical interference by other electrical circuits with "communication" service, including telephone, telegraph and railway signal. The investigation, occupying several years, assumed the character of a research into the intricate phenomena of distant electromagnetic induction, its remote origin in the characteristics and manipulation of power apparatus and its acoustic effects upon telephone service. To present the details of the various tests, methods and apparatus employed has involved the production of fifty special reports now summarized in this general report which draws a series of conclusions and submits and discusses a proposed code of rules for the prevention of the interference in question.

As a scientific research this investigation is invaluable and marks a distinct advance in applied electrical science. In view of the economic importance of telephone and similar service, and of the probable increase in the future in the capacities and voltages of power circuits, there appears a very real and difficult problem to be met in the evolution of the respective arts. To the solution of this problem such research should undoubtedly point the way. In this sense this report deserves marked appreciation. But at this time attention is called not so much to its scientific value as to the economic and legal effects of its code of rules.

Although recognizing a conflict of interests between the respective groups of electrical industries, the investigation was conducted and the rules drawn ostensibly to meet the problem only as a scientific question of demonstrable cause and effect. Unanimously indorsed by a committee purporting jointly to represent the telephone, the railway, and the electric power interests of the state, the rules purport to be, in effect, an agreement among all parties in interest, and as such, approved and adopted by the Commission, have become the law of California. By this process the Commission is led to adjudicate the differences and legislate changes in practise from scientific considerations alone without regard to the broader aspects of the issues involved.

The problem is much broader than that. It involves another scientific aspect as well as questions of inherent rights, of equity, of evolution of the respective industries, and of the policy of the public toward its utilities. Moreover the rules are not mere logical conclusions, and their full effect is not apparent from their text. Read casually, they imply a spirit of friendly cooperation toward some mutual purpose. In results, however, benefits accrue only to one interest, while burdens, even extreme hardships, are laid upon the other. Their full import appears only from careful consideration of each rule in the light of the whole seen from a mature point-of-view.

The partisan point-of-view from which these rules have been formulated is shown by their context. " Since these rules are designed for the protection of communication circuits," (Discussion of Rules, Art. IV.) acknowledges that they are designed to restrain the power circuits. While the specific parties in conflict are somewhat obscured by including the railway interests as a third party and by use of the term " communication " instead of " telephone," yet Rule V. in effect waives all conflict between railway and telephone interests, thus associating them and leaving the power interests alone under restraint. And while the caption " Historical," (first paragraph) in presenting the origin of this action styles it " the outgrowth of certain differences * * * * brought to the attention of the Railway Commission " instead of plainly " a complaint by the telephone lodged against the power interests," it likewise states (fifth paragraph) that this investigation, attributed to the Joint Committee, was in fact already a department of the Pacific Telephone & Telegraph Co. and of well-defined form and character before taken over by the Joint Committee, and also that it was continued (fourth paragraph) by a staff of telephone employees. It thus appears that this measure, instead of being a mutual matter or serving a mutual purpose, is in fact a telephone project from its inception to the conclusions which are formulated into the rules presented.

The specific rules, seventeen in number as grouped under caption II, may be classified as follows:

Mutual obligations respecting the spacing of power from telephone circuits; the uniformity of parallels, and the use of adequate systems of transpositions.

Specifications of power equipment, covering wave-form of generators, charging current of transformers, type and equipment of line switches, style and location of transpositions, and also requiring ammeters in ground neutrals and the use of ground detectors.

Dictation of methods in power distribution, covering balancing of loads, balancing of circuits, and methods of connecting and loading transformers.

Restrictions in operating procedure of power industries, covering line tests and the manipulation of automatics, operation with open-circuits and grounds, measurements of ground currents and the charging of electrolytic arresters.

Stipulations respecting obscure power-circuit effects, requiring the limitation of residuals and the elimination of harmonics.

In discussing the individual rules, the following general considerations should be recognized.

The scope of the restrictions placed upon power interests is without tangible limit. Rule I prohibits " parallelism ", which is defined as lines in such proximity " that the power circuit is liable to create inductive interference * * * *." Note the term " liable to." It is not " has " or " does " but " liable to." The question is one of degree, but no degree being even implied, the rule stands absolute. Since inductive effects are obscure and difficult of determination, the telephone interest may readily find occasion for claiming with some plausibility that almost any power circuit of the State is in parallelism to some slight degree. Where impracticable entirely to avoid parallelism, this rule makes the power circuit subject to the seventeen specific rules classified above.

For the enforcement of these rules far-reaching power of reprisal and dictation is reserved by the telephone interest. Rule " d " successively stipulates, emphasizes, and confirms that the telephone interest " shall have the right to specify the number, type and location of transpositions." in power circuits.

Transpositions constitute the great general measure for naturalizing interference,—the last resort. They are both a hardship in expense and a menace to safety and service, and in degree both are, in general, proportional to the voltage transposed. The right to specify them, therefore, here becomes the weapon of the telephone interest against the power interests for all manner of possible short-comings. Upon high-voltage lines and especially upon tower circuits in good telephone districts, this right carried to logical limits under these rules becomes tantamount to supreme authority. True, the telephone interest is limited as to the frequency of its use,—not oftener than one-sixth mile apart, but this very limit serves but to emphasize the length and breadth and depth of the power here grasped by the telephone interest.

None of the expense or burden of this new regime falls upon the telephone interest. Rule IV provides that " At the option of the (telephone) company * * * * any of the provisions of II and III may be waived." Since II and III comprise in effect the entire code, this provision becomes a blanket release giving the telephone interest immunity from any unwelcome involvement. Thus these rules which in effect " box " the power interests on all sides, notwithstanding their purport of cooperation, leave for the telephone interest a back door of escape always open. It thus, for instance, in paralleling a previous power circuit, could throw upon the power interest the hardship of reconstructing to conform to the rules, while itself evading through this back door any burden whatever.

Turning now to the seventeen individual rules as already classified, or rather to a few of their characteristic provisions; of those specifying characteristics of power equipment, rule

" p " requires power companies to obtain and use generators " giving as nearly as reasonably possible pure sine waves of voltage * * * *". Does this mean that the power companies of California are now using generators of characteristics inferior to those recognized as standard in the industry, or does it mean that electrical manufacturers must now evolve a line of generators of new design and characteristics for the special needs of California trade? Rule " q " raises a similar question as to the exciting current of transformers. Rule " j " prohibits the use of air switches which are now so generally used and from the further development of which so much is expected, while rule " h " requires the general use of oil switches " rendered automatic for short-circuits, grounds and abnormal neutral currents." This calls for a mechanism which has already been sought for many years but never yet produced and, in the opinion of many, beyond mechanical possibility.

Referring to the rules which restrict operating proecedure as now followed; rule " o " requires the charging of electrolytic arresters during the late night, while " m " regarding line testing in cases of trouble, prohibits present prevailing practise and in effect requires the development of new methods and new apparatus for the localization of line faults.

Similarly, rule " n " specifying " * * * a record of hourly measurements of the neutral currents * * *," in effect seems to require a regular corps of attendants at every point of transformation employing a ground connection.

The class of rules respecting obscure phenomena incident to power-circuits is less specific, yet rule " b " requires " special consideration shall be given to the prevention or elimination of harmonics * * *." This is a problem of many years' study by engineers, manufacturers and power companies alike, the solution of which might have saved from financial failure many of the power ventures of the past decade.

Without going further at this time into the many restrictions and their ultimate effects, the above characteristic cases will illustrate the radical nature of the rules, the impossibility of their fulfilment, and the length to which they go in demanding a virtual reconstruction of the power industries to meet the telephone's demands. They express the telephone interest's demand for impracticable ideals. That the results required are in fact impracticable ideals is tacitly recognized throughout the text by the constant recurrence of such evasive expressions as " Every reasonable effort to avoid," (several times repeated), " Every effort," and such vague expressions of degree as " Closely as practicable," " Nearly as practicable," " Most reasonable possible," and " Low as consistent with good practise."

The matter of the rule regarding crossings is of quite a different nature. " Rule " a," after specifying the separation between power and communication lines, continues " The only exceptions to this provision * * * " are crossings, etc., which shall be

" * * * constructed in conformity with the National Electric Light Association specifications * * * *." The specifications here referred to were themselves initiated by the telephone interests of the East and presented through a committee formed under telephone influence. At best they are but proposed specifications since, as a matter of record, the N. E. L. A. as an organization declined to adopt or sanction them. Since this matter occasioned much dispute, it has been generally understood that the question of crossings is specifically avoided in these rules as, in fact, it is in title, headings and otherwise in the text. But nevertheless it is covered here and most effectively. Moreover this brief incorporation of it seems to be without the full approval or knowledge of the Joint Committee, since at least one member still asserts that " These rules have nothing whatever to do with the question of crossings." In this light its interjection here seems somewhat a " joker " on the power interests. Suggestively similar are those terms which reserve to the telephone interest the power of waiving these rules as to itself and of specifying transpositions, and which in their final effects, as already discussed, are so far-reaching.

To briefly review: As seen by the power interests, these rules are radical, without tangible limit of scope, impossible of fulfillment, demand virtual reconstruction of their methods and business, and strain toward impracticable ideals; they have been framed by the telephone interest from an utterly partisan point-of-view, to secure to itself supreme power of enforcement; they have been carried to enactment against the power interests, many in number, competitive and without cooperative organization, by a single nation-wide monoply of vast coordinate resources, in California, as a first step toward similar rules wherever possible.

In conclusion: in the matter of electromagnetic interference there unquestionably is a very real and significant problem to be worked out theoretically by precisely such methods as those here reported. But then the same problem must again be worked out in practise through advance in apparatus and methods. Again the problem lies no more with the cause and its removal than with effects and their prevention; it embraces both. Moreover, by its very nature the problem primarily is that of the complainant, and its solution should first be sought at home. Thus there is force in the current retort of the power interests to the complaints of the telephone interest, that the latter has done as little to protect itself as the power interests have done to protect it. The final solution may be found as much or even more in the evolution of protective and corrective devices for telephone circuits as in the elimination of causes as attempted by these rules. It is quite possible that telephone circuits, being more sensitive, are now somewhat at the mercy of the less sensitive and more rugged power circuits and therefore should have some relief, but such a measure as this can but reverse the relation with far more hardship while accomplishing nothing toward the final and equitable solution of the question.

A suitable code of rules, as scientific deductions reported to a scientific body or, accompanied by its natural counterpart in similar rules for the telephone industry, if adopted by this society, would be entirely proper and useful as a consensus of present opinion subject to future advances. But these rules as law, inflexible to changing conditions and without such counterpart, are without equity or sense of proportion and contrary to economic order. Beyond the direct hardship imposed lies a greater wrong. Through their partisan point-of-view and narrow treatment of the issues, they establish by implication the principles of the power industry's legal liability for all possible effects of their circuits and of the telephone industry's fundamental right, wherever it may go, to an atmosphere free from magnetic influence, regardless of degree or priority of presence.

J. B. Fisken: I am sure a discussion of this paper, more especially of the rules, needs no apology before this body. I believe that rules or statutes should be discussed by engineering bodies when engineering is involved. Now, in anything I may say as to my opinions, I would simply state that I have been handling for a matter of twenty-eight years voltages varying from 90 to 60,000 and I have had quite a little experience. I want to refer to page 1317 under "definitions;" "a. Power Circuits." and "d. Line." These definitions provide for the inclusion in circuits which must be transposed, of arc circuits of voltages of 5,000 volts or more. But the rules do not state how they should be transposed Series arc circuits are quite frequently run with one wire on a street; the return wire may be half a mile away. The people of California may have to string both sides of the circuit across this distance of a half mile to get a transposition or build both sides of the circuit parallel to the telephone line.

I think there has been a mistake made in the arrangement of the rules; as, under Rule 2, section "a," there is a rule which should be arranged under the heading of "Phantoms." A phantom, as I understand it, is something that has no apparent existence. As I regard this rule, and as Mr. Nunn has stated, it has nothing whatever to do with inductive interference; to my mind there is only one thing I can see it has to do with, and that is an imaginary physical hazard which does not exist.

A. H. Halloran: Since the earliest times an honest difference of opinion has always been an incentive to progress. Mr. Nunn evidently believes that this scientific investigation as to means for keeping a proper balance of power in circuits paralleling telephone lines, throws the balance of power too strongly in favor of the telephone company. Yet it should not be forgotten that the power companies have been the aggressors. Telephone circuits existed many years before there were power circuits. The telephone companies have spent thousands of dollars in vainly trying to solve the problem by compensating their own lines. Efforts were also made to adjust the matter legally, but it was recognized that the subject is primarily an engineering problem. Consequently, while it may be admitted that the burden of correction is now laid upon the power companies, their representatives on the committee have recognized that it is only by the true spirit of co-operation tha any mutual understanding can ever be reached. The report is admittedly only preliminary, and the committee stands ready to make any adjustments or corrections which may be found necessary.

A. J. Bowie: I have been greatly interested in the report of the Committee on inductive interference, particularly as this deals with a field of investigation about which little has been written prior to the present time. Insofar as the findings of the report are based on actual tests and data, it furnishes a very interesting study.

The letter of transmittal states: " Therefore the rules are not put forth as being final or complete but must be regarded as provisional and subject to such change as the results of further investigation and experience may determine."

However, experience with which the committee is apparently not familiar has already demonstrated that their recommendations on switches and switching are based on a very unsubstantial foundation. Quoting from the report, section 2, H I J, reads as follows:

> The commonly recognized fact that oil switches produce less severe transient disturbances in power circuits affords the basis for the provisions in the rules dealing with switches and switching.

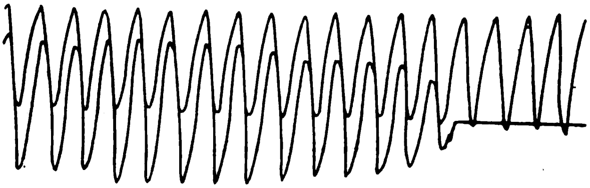
Quoting further from the report, the following rules are laid down to govern switches.

> *H—Switch Equipment.* A power circuit involved in a parallel shall be equipped, between the source of supply and the parallel, with oil switches, all poles of which shall be mechanically inter-connected for simultaneous action. With the exception of stations where an operator is constantly on duty, these switches shall be rendered automatic for short-circuits, grounds, and abnormal neutral currents.
>
> *I—Switching.* All switching on all parts of a system connected to a circuit involved in a parallel, which causes harmful transient disturbances in communication circuits shall be done by means of oil switches, all poles of which are mechanically interconnected for simultaneous operation.
>
> *J—Use of Air Switches.* The use of air switches, on a power circuit involved in a parallel, is prohibited except for purposes of isolating sections of dead line, or for disconnecting transformers under no load. This applies to the entire power system, any circuit of which is involved in a parallel, unless such switching is so remote as not to cause harmful transient disturbances in the communication circuits."

One of the important expenses in the transmission and distribution of power is the cost of high-tension switches. Air switches represent a very material saving to the consumer over the cost of oil switches as their prices will range from about one-third to two-thirds of the cost of the latter for switches of equal capacity. In addition thereto, air switches effect a still more important saving for high-tension work in that they may be located out-of-doors whereas the housing of oil switches in many cases costs as much or more than the switch itself. Therefore the use of air break switches will effect a material saving to the power companies and hence no rulings of any nature should be passed to forbid this saving unless the air-break switches produce an extremely bad and undesirable effect which will more than offset the great saving from the use of this type of switch. Hence it is with great astonishment that I note the report in this respect does not pretend to be based on scientific tests but on what is termed a "commonly recognized fact." At one time it was a commonly recognized fact that the world was flat and the universe revolved around it. It is unfortunately the case in engineering, as in other matters, that theories based on insufficient data obtain partial credence and are accepted without real investigation.

By the use of expensive and complicated apparatus it is possible to establish a very short arc in air in an exceedingly strong magnetic field and to make the arc so established set up high-frequency oscillations. But to accomplish this result requires the use of special apparatus entirely foreign to that used in any air switch construction. It is quite possible that an arc produced under oil might under similar circumstances become oscillatory when sufficient attention is paid to the details of construction to accomplish this result. As it is possible to produce an oscillatory effect in air many engineers without investigation have sincerely believed that the operation of air switches would cause a high-frequency surge, and this has resulted in a certain amount of prejudice against the use of air-break switches.

An interesting article has just appeared in the *General Electric Review* of September, 1914, by Mr. W. P. Hammond, Engineer of the Northern Contracting Company, giving a description of extensive tests on air-break and oil switches, conducted on systems of 44,000 and 110,000 volts, opening loads of several thousand kilovolt-amperes. These tests fully demonstrate the fact that in many respects the air switches are superior to oil switches. Quoting from the article: "In order to get a general check on the voltage surge, set up on the load side on opening the circuit with an air-break switch, a needle point spark gap was connected to two of the phases set accurately for different voltages and the maximum sparking gap noted for each switch under the same load conditions. The same experiment was tried on an oil break switch in the circuit and the maximum sparking distance recorded when the circuit was opened with this switch was greater than with the air break switch." This shows that oil switches cause a greater surge and rise of voltage than air switches. The article further states "The oscillograph records obtained during these tests do not indicate that there is any high frequency set up on the lines by air switches which is especially dangerous to the equipment." Also, "The spark gap test previously referred to in this article would indicate that the surges in the voltage set up by the air-break switch are not so violent as those set up by an oil switch, although this is not in line with the current opinion." Also, "The general conclusion drawn from these tests is that the air break switch will doubtless replace the oil switches for many uses." Thus it is apparent that the air break switches do not set up material oscillations in the circuit. The illustration herewith, from the above-mentioned article, is an oscillograph record showing the conditions when opening a 50,000-volt system and interrupting an energy load of 2500 kv-a. with an air-break switch. The upper curve represents the voltage on the supply system, and the lower curve represents the current. It is of particular interest to note that the current curve tapers off gradually, the time of tapering consuming about six cycles. This is a very important consideration in the action of air-break switches, showing that the introduction of the high resistance of the long arc cuts down the current before the moment of final break, thus lessening the voltage rise over that which occurs with an oil switch, where the break is more sudden. The time of operation of air switches is in general from one to three seconds, provided the switch is not overloaded. The actual time will, of course, depend on the design of the switch, as well as on wind conditions. The time given above is a result of a long series of observations.



SHOWING INTERRUPTION OF AN ENERGY LOAD OF 2500 KV-A. WITH AN AIR-BREAK SWITCH

The conditions of opening of an air switch are commonly misunderstood. A short arc in an air switch will be of relatively little resistance so that until the arc lengthens materially, there will be no substantial change in the current conditions over that obtained prior to the opening of the switch. After the arc has lengthened sufficiently, an effective gradual decrease in the current will occur and will require only a few cycles. Thus, for illustration, if it took the switch in question three seconds from the time of opening the switch until the arc was extinguished, this would last over a period of 180 cycles. During the first 174 cycles, no very material change would take place in the conditions of operation over what existed prior to opening the switch. During the last six cycles, the resistance of the arc increases rapidly, thus diminishing gradually the current up to the point of final break. At worst, even if the switch operation does affect the telephone lines, the period of such operation is exceedingly brief, also, the switch operation is in general very infrequent on high-tension lines, so that even if severe disturbances should be produced the total time during which the telephone service would be affected in a year would be so small as to be practically negligible in comparison to the saving to the companies and consequent saving in the cost of power delivered to the consumer.

From the foregoing the following conclusions are drawn:

1. Air break switches will produce less rise of voltage than oil break switches, and hence will not affect the telephone system as severely as the oil switches.
2. No material high-frequency surges are set up on the opening of air switches.
3. The duration of opening of air switches is somewhat longer than that of oil switches but the total time of such operation is so small as to be negligible in its effect on the telephone service.
4. The advantages of air switches are very much greater than any disadvantages cited.

I might add further that air-break switches are in use for controlling many important lines, among others, the longest line in the world, comprising the system of the Southern Sierras Power Company, which transmits power from Bishop to San Bernardino, a distance of 240 miles. Also, I have installed many air-break synchronizing high-tension circuit breakers for synchronizing high-tension lines, and according to all reports received the operation in synchronizing is perfect, and does not cause the slightest appreciable disturbances of the system.

I am sure that everyone will agree in the suggestion that before drastic rulings on switching are adopted by any commission, more complete investigations should be made as a basis, rather than the unsubstantial basis of "commonly recognized fact."

Geo. S. Humphrey: Referring to the paragraph entitled "Minimum horizontal separation:" I question whether the last three lines of that really mean very much. It says that "Crossings shall be constructed in conformity with the National Electric Light Association's specifications for overhead crossings or other approved equivalent which may be agreed to by both companies." As most of you are probably aware, there was a resolution passed on this subject at the last meeting of the National Electric Light Association. This resolution reads as follows:

> Whereas, at the annual convention of the National Electric Light Association in the year 1911 there was presented a report by the Com-

mittee on Overhead-Line Construction, to which the Executive Committee then gave its qualified approval, since which time the progress in the state of the art and the continued good work done by the Committee have developed recommendations of better practice which the overhead-line-construction committee now presents to this convention;

Therefore, be it RESOLVED, That the thanks of the Association are due and extended to the Overhead-Line Construction Committee for its sacrificing and painstaking efforts, and, in view of the later recommendations of that Committee that the heretofore qualified approval of the 1911 report is hereby rescinded, and that the question of voltage limitation shall be eliminated from any recommendations or reports of any committee of this Association, by inference or otherwise, with relation to overhead-line construction practices, and that any such recommendations or specifications to this or previous conventions by any committee shall not be sanctioned by this Association.

This resolution was adopted by the National Electric Light Association in June, and so at the time these rules were prescribed by the Commission, there was not and is not now any such thing as "National Electric Light Association's Specifications for Overhead Crossings." No such specifications are included in the Handbook on Overhead-Line Construction, which was published at that time.

It appears that in defining telephone circuits, telephone systems of high-tension operating companies are included as a telephone circuit. The term includes any metallic telephone circuit operated by any railroad or other company for dispatching purposes. I just wondered if private telephone systems of transmission companies are included in that definition of the telephone circuit.

In the section of the country with which I am familiar there were formerly two telephone systems, and they have lately been consolidated. Now almost every important road in the country has a telephone line on each side of the road which is owned by the same company. I wonder what the recommendation of the Committee would be as to where the line of the power company should be placed along these roads.

J. C. Martin: I think Mr. Nunn has covered the practical aspects of the question about as well as it can be done. However, from the standpoint of the experience that I have had in connection with transmission and distribution problems in the Northwest, I have a few suggestions to make.

The 5000-volt limitation is particularly bad. The company that I am connected with operates a great many miles of 6600-volt circuit. So far as any records we have, or anything that we have heard from the telephone companies show, we have no trouble due to inductive interference with properly constructed telephone lines. These rules would practically put us out of business as far as the 6600-volt line construction and operation is concerned. That is especially true because of the rule covering transformer connections. Owing to the conditions we have to meet we make very frequent use of the open-delta connection and do not operate any of our single-phase transformers without grounding the secondary neutral.

On the question of telephone lines occupying both sides of the road: I think here in the Northwest, and I believe in most portions of the country as well as the Northwest, you will find that every country road has at least one telephone line that usually succeeds in occupying both sides of the road, and often there are two or more lines that stagger from one side of the road to the other. The lines are ordinarily ground return circuits and the construction adopted is usually the very cheapest that can possibly be used and have the lines stand at all, and no effort is made to even install the ordinary telephone protections. I am wondering, with Mr. Humphrey, what would happen in case a power company desires to build a line of over 5000 volts along such a country road, either in the State of California or wherever these roads might be located, and these rules enforced. The power company could undoubtedly be forced to rebuild such lines completely if these rules were in force. It seems to me absolutely unjust to force the power companies to stand the trouble that is due in many cases entirely to the poor construction of the telephone lines involved.

Like Mr. Nunn, it appears to me, from the wording of these rules, that a large number of important questions of design are left to the sanction and fiat of the telephone company; in other words, the engineers of the power companies are without any voice whatever in the matter as to how their service shall be handled or as to the methods or designs they shall adopt to best serve their customers. I know that in the territory we are serving the burden put upon the company in complying with rules of this sort would practically prohibit the serving of a large number of our customers and prospective customers.

Again, the telephone companies are relieved of practically all responsibility in the matter and the power companies are saddled with the responsibility and expense of avoiding any trouble that it may be necessary to take care of. I believe it will be conceded that the power companies furnish service that is as much of a public necessity as that furnished by the telephone companies. If any action is to be taken, the responsibility of caring for the trouble should be divided equally between the parties involved, and the telephone companies as a whole should be forced to a standard of construction that will be at least equal to that maintained by the power companies.

L. J. Corbett: Entirely apart from the legal aspect of this report I think that we are fortunate in having it before us for its value as a technical contribution. It represents the investigations of a committee which was well equipped; it presents some of its findings, and contains certain recommendations which do indicate to us how we may avoid interference.

There is one thing that attracted my attention at first glance at the paper, and that is in one or two of the definitions, the use of the term "residual." Possibly most of you would not take up such a point as this, but at first glance I wondered which meaning of "residual" was intended. I find that it refers to "the vector sum of the current in the several conductors of a power circuit." We are used to thinking of residual as something left over, a residual charge upon a condenser, residual magnetism in a field, and it seems to me we are using an old word for a new idea, which new idea requires a separate definition for the old word. It does not give us the idea at once as to what is meant, and I wonder if this committee gave any great thought to this matter in drawing up their definitions. It would seem that a word could be found which would connote the idea a little better than this word residual.

In reference to Mr. Fisken's question about the series circuit, I would offer as a suggestion that in such a case, according to this definition of residual, the entire current of the series system would be residual current and the entire voltage, the residual voltage.

Chas. P. Kahler: In the discussion of Rule V the following comment is made:

> *V.* The Committee has undertaken no investigation of cases of parallelism with alternate current railways, but as the seriousness of this class of exposure is recognized it is thought desirable that it be referred to specifically.

However, although the Committee admits that it has made no investigation upon which to base any regulations for such conditions, nevertheless, it has undertaken to make such regulations, as shown by the following portion of Rule V.

> In the present state of the art, no means for completely overcoming inductive interference from such parallels is known, hence, they are to be avoided if possible.

If such rules were in force in the State of Washington, could the Inland Empire System be extended if there was a telephone or power line in the territory where it is proposed to extend it? It is well known that considerable study has been made to eliminate disturbances caused by both alternating- and direct-current railway circuits, and the latest work and information on this subject would indicate that trouble from this source may be overcome. The fact that the railroad companies themselves have to maintain communication circuits makes it necessary to provide means to prevent interference with them. It does not appear to me proper to add rules which may cause unnecessary expense to any electrification proposition unless the effect of such rules is definitely known.

L. T. Merwin: I think you were peculiarly happy in your choice of Mr. Nunn as the first one to be called upon for the discussion of this paper. I was greatly pleased with Mr. Nunn's calm, judicial manner in handling the subject and with the nature of his remarks from the standpoint of a power man. Mr. Nunn, I think, has gone right to the quick of the matter from the standpoint of the power man, and "forewarned is forearmed." This thing has been done in California; most of you gentlemen are from northern states, northwestern states; if such a thing as this is to be put in a legal form in Oregon or Washington or Idaho or Montana I am sure there will be before the respective commissions of these states very well prepared and vigorous opposition, and rightly so, I believe.

I have great admiration for this paper as a scientific document; it puts before us in a very lucid way some things that we all wanted to know, but it puts them also firmly before us in a positive legal way, not bringing out what we may do, but; "Gentlemen, how do you like this? This is what you have to do." It is written by a body of men of undoubted scientific attainments and is presented to us as their findings, but presented as their findings after those findings have been put into legal form. It isn't here for our discussion as to the merits of the thing from an engineering standpoint, it comes as an absolutely closed book, and I feel very sorry for the power companies operating in California.

Mr. Humphrey brings up the point as to what will happen in a legal way, or how is one to interpret the situation, if the communication company is also the power company, considering its own communication lines. Mr. Nunn very clearly stated what could be done: The power company can simply sneak away from itself out of that "back door." That is all right and is easy.

We have a line of our own; I have been troubled with induction on that line for some seventeen months. On about fifty miles of our power line we had considerable difficulty owing to the topography of the country. It passes down along the north bank of the Columbia gorge. I have found it absolutely impossible, try as I may, up to the present time to neutralize the inductive effects on the telephone line. The power line is not transposed. However, we have done something else than transposing, and it seems to me that the telephone company might do the same. I have simply given up all efforts to get rid of induction, I have accepted it as a fact, and then looked around to see if I could kill it or get rid of it insofar as the receiver of the telephone instrument was concerned, and I believe that I have succeeded. Now if a power company can succeed surely the minor disturbances that arise on the telephone lines can be taken care of by the telephone companies. It seems that those slight residual effects—I mean residual not in the sense in the paper—can still be neutralized. Very briefly and as an aid to others who are having the same trouble, I have learned through the manager of the Federal Wireless Telephone Company in Portland of a high-power transmitting instrument made by some private firm in Seattle, the name of which I shall be glad to give to any one. I have arranged reactors and condensers into a resonant circuit at the instrument, and found I could actually neutralize the inductive effects of the power line at the instrument. With an ordinary transmitter the working current is not strong enough to force through the series impedance of this arrangement. By using this high-power telephone transmitter I found I could get sufficient amplitude of talking current. I simply mention this as a possible relief to other power men who have had the same trouble with their own telephone lines.

C. E. Rogers (by letter): This report is very interesting as it covers a subject to which much space in the scientific press has been devoted in a qualitative manner, but, like previous papers, it does not give any quantitative results. I realize that many more formulas are yet to be derived in order to present this subject with mathematical accuracy, such as has been done in the calculation of corona losses, and I regret that at least one appendix has not been devoted to the calculation of the voltage and current induced in the communication circuits of one of the exposures mentioned. In order to present the rules that have been recommended, these data must have been accumulated, and an appendix containing quantitative information would receive deserved attention and valuable criticism.

A. J. Bowie, Jr. (by letter): Supplementing my oral discussion of the report of the inductive interference committee, the most direct and authoritative evidence on results of opening air switches can naturally be obtained from companies making extensive use of apparatus of this nature. Consequently for further investigation of this subject, I have written to The Pacific Power Company, Bodie, California, and The Southern Sierras Power Company, Riverside, California, both of which Companies employ air switches, almost exclusively, for their high-tension systems.

I have addressed the following questions to these companies:

(1) Have you on your lines any material length of what may be termed parallel to the communication circuits?

(2) To what company do the communication circuits belong?

(3) Has your company ever received complaints from owners of communication circuits about the inductive effect of your power lines?

(4) Have any specific complaints ever been received of trouble in communication circuits from switch operation?

(5) If so, what is the general nature of such complaints, *i.e.* as affecting the interference with communication or as affecting any safety or any other apparatus connected to their system.

In reply thereto, I have received the following answer from Mr. C. O. Poole, Chief Engineer, Southern Sierras Power Company:

(1) We have several cases that might be used under the term parallel to the communication circuits.

(2) The communication circuits belong to The Pacific Telephone &

Telegraph Co., the Southwestern Telegraph Co. and The Western Union Telegraph Company.

(3) We have received several complaints from the Pacific Telephone & Telegraph Co., Southwestern Telegraph Co., and the Interstate Telegraph Co., of the inductive interference with their communication circuits.

(4) We have not received any specific complaints of disturbances caused by the operation of air switches. We have however, received complaint from the disturbances of the service caused by the charging of the electrolytic lightning arresters. We are preparing to install current limiting resistors which will probably reduce the cause for complaint.

Reply from Mr. W. N. Chatfield, General Manager, The Pacific Power Company:

(1) Telephone lines parallel our transmission line for a distance of 125 miles, and are on the same poles as the transmission line for a distance of 66 miles.

(2) Telephone lines used in connection with power operation and not for public use.

(3) We have received no complaints on account of inductive effects on the telephone lines. Naturally there is a good deal of induction on the telephone line but **not** so that it interferes in any way with the operation of same, and as the line is for our own use, naturally no one has any complaint to make.

(4-5) We have not had any trouble to amount to anything in our telephone system caused by switch operation on the transmission line.

It is greatly to be regretted in making this investigation, that the committee did not avail itself of the experiences of some of the largest users of air switches on the Pacific Coast. Had it done so, I feel sure its report on this subject, would have taken a very different aspect.

All the evidence available, shows very strongly that oil switches will produce more severe disturbances than air switches on their own, as well as on neighboring lines. There is one feature of the report which is most inconsistent, namely, the prohibition of air switches, and at the same time the allowance of the use of electrolytic lightning arresters. From the very nature of the electrolytic arrester, the breaking of the current either when the arrester is being charged, or when the arrester is operating, is very abrupt, and hence very apt to cause undesirable effects on parallel lines. To be at all consistent, the electrolytic arrester should have been included in the general prohibition of the subject of arcs in air.

Even though oil switches will cause more severe disturbances than air switches, there is certainly no reason sufficiently strong, at the present time, to render advisable in any way the prohibition of any special type of switch, and legislation in this direction is a definite step backwards.

Joint Committee on Inductive Interference: The above discussion of the report of this Committee discloses many misunderstandings, some of the clear meaning of the recommendations, but mainly of the scope and the spirit of the Committee's work. This scope and spirit may perhaps be best expressed in words as follows:

The State of California must have both electric power and electric communication. The former now conflicts with the latter and the conflict is becoming more serious year by year as the two services expand. When the two services approach their ultimate development of universal power distribution on the one hand and universal communication on the other hand, the conflict will greatly hamper the communication service if the power service is permitted to expand with no limitation of its inductive effects. The greatest good to the greatest number, which is in this case the best and cheapest power service combined with the best and cheapest telephone service to the people of the State, will be obtained by the imposition of such burdens on the power service as will result in improvements to the telephone service greater than the burdens imposed. The Committee contends that each of the burdens imposed on the power service by the rules recommended will result in an improvement of the telephone service to the citizens of the commonwealth totally out of proportion to the interference of those same rules with power service to the citizens of the commonwealth. This view has been kept clearly in mind in the formulation of each ruling recommended to the State Railroad Commission.

The Committee admits that "benefits accrue only to one interest while burdens are laid upon the other." Since by no stretch of the imagination can the inductive effects of communication circuits as now operated (wireless excepted) be considered as interfering with power circuits, the latter will not be benefited. No engineer should intimate that such a benefit should be sought. The Committee does not admit, however, that the burdens are "extreme hardships," but contends that these burdens will in all cases do more good than harm to the public services of the State as a whole.

Admittedly, "the Commission is led to adjudicate the differences and legislate changes in practise from scientific considerations alone * * * *." and all praise is due the Commission for this action. But the Committee submits that there the "broader aspects of the issues involved," viz:, equity, inherent rights, the evolution of the respective industries, and the policy of the public toward its utilities, are all covered by or are subordinate to the principle of the greatest good to the greatest number. This has been the chief consideration followed throughout.

The Committee does not agree that the rules "establish by implication the principle of the power industry's legal liability for all possible effects of their circuits," but does contend that they establish in California the power industry's legal liability for unnecessary, unwarranted or avoidable inductive effects where such effects will work hardships materially greater than those necessary to avoid them. Neither do the rules establish "the telephone industry's fundamental right, wherever it may go, to an atmosphere free from magnetic influence, regardless of degree or priority of presence." They do establish the telephone industry's fundamental right, wherever it may have metallic interexchange circuits (not subscribers' circuits) to an atmosphere free from inductive influences so great as to cause harm more serious than the burdens imposed on the power industry by reducing such influence.

The Committee admits the justice of the criticism (favorable or unfavorable) that "the scope of the restrictions placed upon power interests is without tangible limit." The absolute impossibility of determining in the general case, for example, to just what extent the residual current in a power circuit can be reduced with a burden on the power system less than the benefit to the telephone system, makes it necessary to use the expressions criticised, "closely as practicable", "every reasonable effort", "low as consistent with good practise," etc.; unfortunately, perhaps, the communication interest is the party best able to judge the effects of these intangible quantities and this interest has been given in some cases the right within fixed limits to specify quantities, on the assumption of co-operation, with the Commission as a court in case of disagreement. The Committee hopes that its future work will make it possible to be more explicit with respect to such quantities as are capable of quantitative analysis into burdens and benefits.

The Committee admits also that the communication interests have much of their future life to gain and nothing to lose by the investigation and its results, and that the power interests have nothing to gain and little to lose as compared to the gains of the other party; for which reason the telephone interests have contributed to the work more men, funds and equipment than have the power interests, and have naturally taken a deeper interest in the work. Admittedly also, the telephone interests of practically the whole country have been pitted against the power interests of California, which in this work were not "competitive and without cooperative organization." But the Committee denies that the natural zeal set up by this greater incentive has been effective in making its recommendations depart from the principle of the greatest good to the greatest number.

A more nearly just criticism is that "the problem lies no more with the cause and its removal than with effects and their prevention," but the Committee has not yet found many opportunities for improvement of telephone plant or operation because the telephone interests have already made many such improvements.

It is not true that "none of the expense or burden of this new regime falls upon the telephone interest." The rules recommended cover retransposition of the telephone lines to match power line transpositions, which is no small requirement, since many telephone transposition points are required for each power transposition, and with a heavy telephone lead there must be a large number of transpositions at each transposition point. It is hoped that the future work of the Committee may develop other possibilities of improvement of the telephone plant.

The more specific criticisms of details of the report are subject to the following comments:

The requirement of wave shape of synchronous machinery does not mean that the power companies of California are now using generators of inferior characteristics, nor does it mean that "electrical manufacturers must now evolve a line of generators of new design and characteristics for the special needs of California trade." It does mean that due weight should in the future be given the matter of wave form from the standpoint of its possible inductive effect on other circuits. There is nothing extreme contemplated. The Standardization Rules of the Institute are set up as the limiting requirements.

With regard to the exciting current of transformers, investigation will show that the 10 per cent limitation covers all ordinary practise and good design, but excludes densities so excessive that they might be considered "freaks."

The requirement of oil switches rendered automatic for abnormal neutral currents, far from being beyond mechanical possibility, calls only for the addition of the most simple kind of an overload trip connected in a circuit of ground potential.

The rule regarding line testing in case of trouble does not "prohibit present prevailing practise" as far as California is concerned, and does not "require the development of new methods and new apparatus for the localization of line faults," but does enforce the best prevailing California practise, without new methods or apparatus.

The record of hourly measurements of neutral currents is called for only at the main generating and substations, at most, if not all of which, operators are on duty at all times, for which reason this rule does not "in effect seem to require a regular corps of attendants at every point of transformation employing a ground connection."

Harmonics of either voltage or current in a power system, far from being "a problem of many years study by engineers, manufacturers and power companies alike, the solution of which might have saved from financial failure many of the power ventures of the past decade," are usually inappreciable so far as the operation of the power system itself is concerned, and in the few extreme cases where they are so appreciable, they can be reduced without material expense.

The only rule affecting construction at points of close proximity is not outside the scope of the Committee's work, as an examination of that part of the report covering the formation of this committee would show that the Railroad Commission called for recommendations "tending to minimize inductive interference ***and physical hazard*** arising from parallelism of different classes of circuits."

The specifications referred to as those of the N. E. L. A. are well known in California as those embodied in the joint report of the Committee on overhead line construction of the N. E. L. A., the High-Tension Transmission Committee of the A. I. E. E., the committee on power distribution of the A. E. R. A., and other committees, and were referred to by the above abbreviated name since the same name is used by the Railroad Commission of the State of California in its General Order No. 26 covering overhead crossings.

Series arc circuits are not constant potential in character and are therefore excluded from the rules under the definition of power circuits.

The criticism referring to roads with telephone lines on both sides is generally inapplicable, as most such duplication is of subscribers' circuits, which are excluded.

Some other criticism might be similarly shown to be due to a lack of care in reading the report or of familiarity with the subject.

The criticism of the ruling on the use of air switches has been based on an entire misinterpretation of the spirit of the work. The Committee stated that the reason for this ruling was the commonly recognized fact that oil switches produce less severe transient disturbances in power circuits. While this may not be true so far as voltage rise in the power circuits is concerned, the disturbances which affect by induction neighboring communication circuits are far more severe when air switches are used than when oil switches are used. The disturbance of a power circuit due to switching that causes the greatest inductive interference is the breaking of one or two phases in advance of the other two or one phase. In case of a system with neutral grounds this action gives a large momentary ground return current in the power circuit. In case of an isolated system this action gives momentary application of full line voltage to only one or two conductors, with no balancing voltage on the other conductor or conductors. Either result causes inductive effects excessive as compared with normal operation. A properly constructed oil switch gives more nearly simultaneous interruptions in all poles, hence this inductive effect is of shorter duration. The published data on which this ruling has been criticised give the following information on this point:

> The maximum time necessary in which to interrupt the arc in any of the 50,000-volt tests was 25 seconds and the minimum 2 seconds, the average time for a large number of the tests being 6 seconds. The average time necessary to interrupt the arcs in the 110,000-volt test was 7 seconds, the maximum being 16 and the minimum 3. This means that the air-break switch requires anywhere from 120 to 1500 cycles in which to interrupt a circuit, while the oil switch may accomplish this result in half a cycle. (*General Electric Review*, Sept. 1914, page 868).

Other tests on oil switches show breaking of all three phases within a small fraction of a cycle. With air switching requireing several hundred cycles to break the circuit, the instant of breaking of each phase depends upon atmospheric conditions, and the three breaks are separated by far longer time intervals than those of oil switches. The excessive residual currents and voltages during these time intervals give inductive effects commonly described by the telephone colloquialism " a bat in the ear." The Committee has records of many cases of temporary injury to hearing both from air switching, and from the use of oil switches not properly interconnected for simultaneous action. Members of the Committee represent by far the largest users of both air and oil switches on the Pacific Coast and also represent interests having by far the largest number of parallels existing in California, if not in the world. The experience of the interests represented amply confirms the scientific bases for these rulings.

A. H. Babcock (by letter): If the minutes of the meeting at which the Joint Committee was organized could have been published with the report, certain criticisms, perhaps, would have been worded differently. The minutes are too lengthly for publication, even in abstract, but the history of the organization of the committee as recorded therein is now given to show the reasons for the investigation, the spirit in which it was undertaken and prosecuted, and the representative character of the members of the committee.

Several complaints had been made to the Railroad Commission by the Pacific Telephone & Telegraph Company, against inductive interferences by certain power companies' circuits. Tests to determine causes and remedies had been carried on for two months by the companies involved, working with the authority of the Railroad Commission Engineering Department. The results promised so much that, at the request of the chief engineer of the Railroad Commission, a general meeting was called " between representatives of various telephone, telegraph and power companies of California, and representatives of the Railroad Commission of the State of California, for the purpose of appointing a committee to conduct tests and gather information with reference to induction matters, both applying to cases now before the commission, and generally throughout the State." (Minutes).

Invitations to appear at the meeting were sent to every telephone, telegraph and power company operating within the State. Twenty-three companies responded by representative appearances. After a preliminary discussion the Railroad Commission requested all the power men to meet in one room, all the telephone and telegraph men to meet in another room, the two groups each to name four men to serve on the committee, (subject to the approval of the commission), with four members of its engineering department staff, and one from the railway interests, not included with either of the two groups in adverse interest, because the railways operate both power and communication circuits.

The president of the Railroad Commission in opening the meeting above mentioned said, " It is distinctly understood on behalf of the commission that we desire to have this committee appointed representing the power companies and the telephone and telegraph companies and this commission, and that, of course the recommendations of this committee will be very persuasive on the commission, but * * * * the commission will formulate the rules we * * * * believe we can get permanent results that will help us in the future on these matters of construction, and we desire it understood specifically that it is to be carried on not exactly under the direction but under the supervision of the commission with a view of a recommendation to this commission."

The personnel of the committee selected is given below.

Representing Railroad Commission:
- Mr. R. A. Thompson, Chief Engineer.
- Mr. A. R. Kelley, Assistant Engineer.
- Mr. James T. Shaw, Assistant Rate Expert.
- Mr. R. Emerson Hoar, Assistant Rate Expert.

Representing Railroad Interests:
- Mr. A. H. Babcock, Consulting Electrical Engineer, Southern Pacific Company.

Representing Telephone and Telegraph Interests:
- Mr. A. H. Griswold, Plant Engineer, The Pacific Telephone and Telegraph Company.
- Mr. R. W. Gray, Division Superintendent, Western Union Telegraph Company.
- Mr. C. H. Temple, General Manager, United States Long Distance Telephone Company.
- Mr. L. M. Ellis, General Manager, Union Home Telephone Company.

Representing Power Interests:
- Mr. H. A. Barre, Electrical Engineer, Pacific Light and Power Corporation.
- Mr. Louis Elliott, Engineer, Great Western Power Company.
- Mr. P. M. Downing, Engineer, Pacific Gas and Electric Company.
- Mr. J. E. Woodbridge, Chief Engineer, Sierra and San Francisco Power Company.

The organization and personnel of the Joint Committee on Inductive Interference were approved by the Railroad Commission on January 6, 1913, and the committee thereupon proceeded with the necessary tests and investigations.

Since the formation of the committee, through additions, resignation or death, the personnel of the committee has changed as follows:

Mr. Louis Elliott resigned and Mr. J. A. Koontz, Engineer of the Great Western Power Company, was appointed in his place.

Mr. V. V. Stevenson, Electrical Engineer of the Postal Telegraph Cable Company, and Mr. L. N. Peart, General Superintendent of the San Joaquin Light and Power Company, were added to the original membership by action of the committee.

Mr. R. A. Thompson, Chairman of the Joint Committee, resigned. Mr. W. C. Earle, his successor as Chief Engineer of the Commission, was elected to membership and chairmanship. Subsequently Mr. Earle resigned and Mr. Richard Sachse, then Acting Chief Engineer, now Chief Engineer of the Railroad Commission, was elected to membership and chairmanship.

Mr. L. M. Ellis resigned and Mr. R. W. Mastick, Transmission and Protection Engineer of The Pacific Telephone and Telegraph Company, was elected to membership.

Mr. H. S. Warren, Electrical Engineer of the American Telephone and Telegraph Company, was elected to honorary membership.

Mr. James T. Shaw, Secretary of the Joint Committee, resigned. Mr. A.R. Kelley was elected to the office of secretary. The vacancy in membership created by the resignation of Mr. Shaw was later filled by the election of Mr. A. L. Wilson, Assistant Rate Expert of the Railroad Commission. Mr. James T. Shaw was elected to honorary membership.

The death of Mr. L. N. Peart created a vacancy in membership which was filled by the election of Mr. J. P. Jollyman, Engineer of Electrical Construction of the Pacific Gas and Electric Company.

Mr. A. R. Kelley resigned and the vacancy was filled by Mr. A. F. Bridge, Assistant Electrical Engineer of the Railroad Commission.

The Chief Engineer of the Railroad Commission always has been Chairman of the Committee.

The power companies whose officers are named above are the ranking companies of this State, in respect to age, extent of system, and magnitude of interests involved. In at least these respects they may be compared with any other similar interests elsewhere. Their representatives have carried out the investigation in a spirit of non-partisan scientific search for the facts, and for the remedy of a condition, in a fashion that repeatedly has aroused the whole-hearted admiration of the other members of the committee.

The report represents the best efforts of those who signed it. Every sentence was studied carefully. Not one was passed for final copy until every member had been given full opportunity to present his views, and often, the final vote was not polled until certain members were satisfied that every man present understood the full effect of the vote on both sides of the question. In every case the vote was unanimous.

MEETING AT NEW YORK, MARCH 12, 1915. See page 59, Sec. I
MEETING AT CLEVELAND, MARCH 18-19, 1915. See page 59, Sec. I

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Vol. XXXIV **March, 1915** No. 3

A. I. E. E. Meeting in New York, March 12, 1915

The 305th meeting of the American Institute of Electrical Engineers will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on Friday, March 12, at 8:15 p.m. This will be a joint meeting of the A. I. E. E. and the New York Section of the American Electrochemical Society, and two papers will be presented, as follows: *Fixation of Atmospheric Nitrogen*, by Leland L. Summers of the A. I. E. E., and *The Cyanamide Process*, by Frank B. Washburn of the A. E. S. The former paper is printed in this issue of PROCEEDINGS and advance copies will be distributed at the meeting.

At the close of the technical session a smoker will be held and light refreshments served in the A. I. E. E. rooms on the 10th floor of the building. Members of the American Electrochemical Society are cordially invited to attend the smoker.

A.I.E.E. Cleveland Meeting, March 18-19, 1915

A meeting of the A. I. E. E. will be held on March 18 and 19, 1915, in Cleveland, Ohio, the arrangements for which are in charge of the officers of the Cleveland Section and the Industrial Power Committee of the Institute. The headquarters of the meeting will be at the Hollenden Hotel and the technical sessions will be held in the banquet room. The technical papers are all published in this issue of the PROCEEDINGS and reprints of these papers will be available without charge upon application to Mr. E. H. Martindale, National Carbon Co., Cleveland, O., and will be distributed at the meeting. The program of the meeting is as follows:

Thursday, March 18

9:30 A.M.

Address of welcome by Mayor Newton D. Baker.

1. *Application of Electricity to the Ore Handling Industry*, by C. P. Gilpin.
2. *Line Disturbances Caused by Special Squirrel-Cage and Wound-Rotor Motors when Starting Elevators and Hoists*, by J. C. Lincoln.

12:00 NOON

Luncheon with the Electrical League of Cleveland.

2:00 P.M.

Inspection trips, details to be announced at the meeting.

7:00 P.M.

Informal banquet, Hollenden Hotel.

Friday, March 19

9:30 A.M.

3. *Answers to Some Questions on Electric Arc Welding*, by J. F. Lincoln.
4. *Troubles Encountered in the Operation of Carbon Brushes on D-C. Generators and Motors*, by E. H. Martindale.

2:00 P.M.

5. *Fractional Horse-Power Motor Load*, by Bernard Lester.
6. *Factors Involved in Motor Applications*, by D. B. Rushmore.

Pittsburgh Meeting, April 15-16, 1915

A two-day meeting of the Institute is to be held in Pittsburgh, Pa., April 15 and 16, 1915, under the auspices of the Industrial Power Committee and the Pittsburgh Section. The program for this meeting will be published in the April PROCEEDINGS.

Third Midwinter Convention, New York, February 17-19, 1915

The third Midwinter Convention of the Institute, held at the Institute headquarters, Engineering Societies Building, New York, was opened on Wednesday morning, February 17, with an introductory address by President P. M. Lincoln, and closed with the session on Friday afternoon, February 19. The sessions were held in the auditorium. The technical papers, covering a variety of subjects, including papers secured by the Committees on Transmission, Electrophysics, Electric Lighting, and Use of Electricity in Marine Work, were presented without deviation from the program published in the February PROCEEDINGS.

The total registered attendance at the convention was 464, of which number 378 were members of the Institute.

Following the technical sessions Wednesday morning and afternoon, the session on Wednesday evening was devoted to a discussion of " The Status of the Engineer." The opening address was presented by Mr. Lewis B. Stillwell, and he was followed by Messrs. E. W. Rice, Jr., E. M. Herr, Alexander C. Humphreys, George F. Swain, H. G. Stott and J. J. Carty. These addresses are to be published in a future issue of the PROCEEDINGS.

On Thursday afternoon some 75 members and guests were taken uptown in special motor buses and made an inspection trip through the new power station of the United Electric Light and Power Company, at 201st Street and the Harlem River. They were shown in groups through the entire plant.

On Thursday evening a subscription dinner-dance was given in the grand ball-room of the Hotel Astor. About 350 members and guests participated. Dancing began immediately after the dinner and continued until the early hours of the following morning.

The technical session on Friday morning was devoted to the subject of the precipitation of fumes, smoke, dust, etc., by electrical means. Three papers were presented, after an opening address by Dr. F. C. Cottrell, in which he gave a historical sketch of the steps in the development of the art. An interesting feature of this session was the demonstration of electrical precipitation by experimental apparatus set up on the stage of the auditorium, in connection with the presentation of Mr. Linn Bradley's paper. Motion pictures were also exhibited, showing the operation of different installations described in the paper.

The concluding session, on Friday afternoon, was taken up by the discussion on Prof. E. E. F. Creighton's paper on *Electrical Porcelain.* Mr. A. O. Austin presented lantern pictures illustrating tests of insulators and insulator parts.

Directors' Meeting, New York, February 19, 1915

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, New York, on Friday, February 19, 1915, at 4:30 p.m.

There were present: President P. M. Lincoln, Pittsburgh, Pa.; Past-President C. O. Mailloux, New York; Vice-Presidents H. H. Barnes, Jr., New York, N. W. Storer, Pittsburgh, Pa., and Farley Osgood, Newark, N. J.; Managers C. A. Adams, Cambridge, Mass., J.Franklin Stevens, Philadelphia, Pa., William B. Jackson, Chicago, Ill., William McClellan and A.S. McAllister, New York, L.T. Robinson, Schenectady,

N. Y., Frederick Bedell, Ithaca, N. Y., John H. Finney, Washington, D. C.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $9,391.23 was ratified.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred one Associate to the grade of Member, elected four applicants as Members and 108 as Associates, and ordered the enrolment of 109 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

The Meetings and Papers Committee reported progress on the arrangements for the Institute meetings to be held in Cleveland, Ohio, March 18-19, and Pittsburgh, Pa., April 15-16, under the auspices of the Industrial Power Committee, with the cooperation of the Cleveland and Pittsburgh Sections, respectively.

The Secretary announced the appointment of the following representatives and committeemen by the President since the last meeting:

Professor P. H. Daggett, representative of the Institute at the inauguration of Edward Kidder Graham as President of the University of North Carolina, Chapel Hill, N. C., April 21, 1915.

Mr. Wilfred Sykes and Mr. H. H. Clark, delegates to attend the meeting of the American Institute of Mining Engineers, February 16-18, 1915.

Panama-Pacific Convention Committee: W. W. Briggs, Chairman, A. H. Babcock, H. H. Barnes, Jr., A. M. Hunt, A. G. Jones, H. A. Lardner, L. T. Robinson, Harris J. Ryan, George F. Sever, J. T. Whittlesey, and C. J. Wilson.

The Secretary announced the appointment by the President of the following as members of the Tellers Committee to canvass and count the nomination and election ballots for Institute officers for 1915-1916, as provided in the constitution: Frederick Borch, Chairman, R. C. Darrow, Harry B. Hammond, W. S. Hoyt, C. A. Rohr. These appointments were confirmed by the Board.

The Standards Committee reported that at the last meeting of the committee, held on January 30, 1915, it was deemed desirable to send two delegates to London to confer with the British Engineering Standards Committee before the adoption of their rules, which it was understood were to be adopted in the near future. The object of the conference is to eliminate, if possible, any material outstanding difference between the electrical engineering standardization rules of Great Britain and of America, in the interest of engineering standardization. Messrs. H. M. Hobart and C. E. Skinner were unanimously chosen as the committee's representatives, and in view of the desirability of immediate action, President Lincoln appointed these delegates, subject to ratification by the Board. The Board voted unanimously to confirm these appointments.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

Guide for Preparing Technical Papers

BY D. B. RUSHMORE

There undoubtedly exists the necessity for some more or less detailed directions concerning the points to be considered in the preparation of papers for professional societies. There are in the membership of such organizations a large number of young men who, either by reason of education or of lack of practise, are not familiar with the best and easiest methods for the production of literary results and to whom such a guide would undoubtedly be of considerable assistance. That there may be many older men who are in the same position need not be discussed.

In connection with the work of one of the technical committees an effort has been made to develop such a guide, but its usefulness would not be limited to any committee or to any society.

In order to obtain the best results it has been the desire to bring together as many suggestions and to focus as much discussion on this as possible, and with this idea a tentative outline, which has already been circulated within narrow limits, is published herewith, with the request that all criticisms and suggestions upon it will be welcomed by the writer, who is desirous of having this matter in shape before the end of the administrative year.

SUGGESTIONS FOR THE PREPARATION OF A PROFESSIONAL PAPER, AND PRINCIPLES INVOLVED IN TECHNICAL WRITING

- Occasion for Writing.
- Class of Readers.
  - Laymen.
  - Specialists.
- Classification of Engineering Writing.
  - Description.
  - Narration.
  - Exposition.
  - Directions.
  - Criticism.
  - Argument.
- General Principles.
  - Accuracy.
  - Completeness.
  - Length and Economy.
- Preparation.
  - Outline and Synopsis.
  - Collection of Data and Illustrations.
  - Investigations regarding preceding publications on the same subject.
  - References and credit to previous authors.
- Outline of Paper.
  - Title (Suggesting the Subject.)
  - Summary or Abstract. (Brief abstract of the main features of the paper.)
  - Introduction. (Definition of the subject to be written up so as to give the reader a clear understanding of the subject which the paper is to cover.)
  - Body. (Solution of the problem. Should include all parts or points which would be advantageous for the reader to consider. Description of each part and explanation of the relation of the parts to each other.)
  - Conclusion. (Should include a brief summary of the points which in the body of the paper were brought out in detail. Suggest some new useful property or application.)
  - Bibliography. (On many subjects it is advantageous to give a list of references to previous articles on the subject.)

Past Section Meetings

Boston.—January 30, 1915, Auditorium, Engineers Club. Subject: Industrial Power. Paper: "Industrial Power Applications," by D. B. Rushmore, illustrated by lantern slides. Attendance 80.

Chicago.—January 25, 1915. Subject Electric Railways. Paper: "Economies in Power Consumption in Electric Railways," by N. W. Storer. Joint meeting with Western Society of Engineers. Attendance 80.

Cleveland.—January 20, 1915, Cleveland Telephone Building. Subject: Telephony. Paper: "The Telephone and Its Development," by N. Anderson. Inspection of exchange of Cleveland Telephone Company. Attendance 62.

Detroit-Ann Arbor.—January 15, 1915, Engineering Building. Paper: "The Growth of a Modern Utility," by J. D. Gordon, illustrated by moving pictures. Attendance 60.

January 29, 1915, Detroit Engineering Society Club Room. Paper: "Shawinigan Falls Power Development," by T. J. MacKavanagh, illustrated with lantern slides. Attendance 50.

Fort Wayne.—January 29, 1915, Commercial Club. Address by Mr. E. S. Myers on "The Indiana Utilities Commission and Its Effect on the Central Station." Attendance 12.

Indianapolis-Lafayette.—January 15, 1915, Indianapolis, Ind. Address by Mr. B. F. Miessner on "Selenium, Its

Applications and Possibilities in Electrotechnics," followed by demonstration of the uses of the selenium cell. Attendance 101.

Los Angeles.—January 19, 1915, Chamber of Commerce. Paper: "The Diesel Engine," by Walter H. Adams. Attendance 72.

Lynn.—January 23, 1915, New American House, Boston. Fourth Annual Banquet of Lynn Section. Short addresses by President P. M. Lincoln, Mr. H. A. Hornor, Prof. Elihu Thomson, and Prof. C. A. Adams, followed by address on "Neutrality" by Prof. Albert Bushnell Hart. Attendance 161.

February 3, 1915, General Electric Works, West Lynn. Lecture by Major J. A. Shipton, U. S. A., on "A Modern Army in the Field," describing in detail various features of military operations. Attendance 410.

Minnesota.—January 28, 1915. Radisson Hotel, Minneapolis. Address by Mr. Chas. L. Pillsbury on "Public Utilities Valuation and Principles Entering into Rate Making." Attendance 150.

Panama.—January 24, 1915. Balboa Heights. Discussion of questions relating to electrical features of canal. Attendance 30.

Philadelphia.—January 20, 1915, Franklin Institute. Subject: Railway Electrification. Paper: "Conditions Affecting the Success of Main Line Electrification," by W. S. Murray. Joint meeting with the Franklin Institute. Attendance 300.

Pittsburgh.—January 12, 1915. Oliver Building. Lecture by Dr. Saul Dushman on "Recent Views on Matter and Energy," illustrated with lantern slides and experiments. Attendance 175.

Pittsfield.—January 29, 1915. Hotel Wendell. Paper: "Modern Theories of Electricity," by Dr. Irving Langmuir. Attendance 70.

Portland.—February 2, 1915. Paper: "The Load Dispatching System of the Portland Railway, Light and Power Company," by R. R. Robley. Attendance 40.

Rochester.—January 22, 1915. Paper: "Automatic Block Signals on the Rochester Suburban Lines of the New York State Railways," by C. L. Cadle. Attendance 56.

San Francisco.—January 22, 1915, Native Sons Hall. Subject: Rate Control. Paper: "The Best Control of Public Utilities," by Frank G. Baum. Joint meeting with N. E. L. A. Attendance 100.

Schenectady.—January 19, 1915, Edison Club Hall. Paper: · "Recent Developments with X-Rays," by W. D. Coolidge; paper illustrated with lantern slides and experiments. Attendance 245.

February 2, 1915, Edison Club Hall. Paper: "The Physical Chemistry of the Blood." Attendance 200.

Seattle.—January 25, 1915, Central Building. Papers: (1) "The Distribution System of the City of Tacoma," by B.W. Collins; (2) "The Underground D-C. Distribution System of Seattle," by Mr. Hoge; (3) "The Underground A-C. Distribution System of the Municipal Lighting Company in Seattle," by W. J. McKeen; (4) "A 13,000-Volt Distribution System," by E. J. Beery. Attendance 36.

Spokane.—December 18, 1915, Chamber of Commerce Building. Papers: (1) "The Electrical Features of the Panama Canal," by D. B. Rushmore; (2) "Some Features of the Practical Operation of High-Tension Substations," by J. P. Byron. Attendance 33.

St. Louis.—December 9, 1915, Engineers Club. Meeting was devoted to a discussion of the new A. I. E. E. Standardization Rules. Attendance 38.

January 13, 1915, Engineers Club. Paper: "The Manufacture and Use of Efficiency Instruments," by John W. Esterline. Attendance 29.

Toledo.—February 3, 1915, Toledo Commerce Club. Address by Mr. W. A. Hill on "Application of Electricity to Industrial Plants," with special reference to the automobile industry. Attendance 19.

Urbana.—January 21, 1915, Electrical Laboratory, University of Illinois. Illustrated address by Mr. A. D. Bailey on "Increasing Importance of Coal in the Manufacture of Electrical Energy." Attendance 90.

Washington.—January 12, 1915, Cosmos Club Hall. Subject: Railway Electrification. Paper: "Electric Railways," by John F. Layng. Attendance 47.

Past Branch Meetings

Arkansas University.—January 18, 1915. Illustrated lecture on "The Manufacture of Portland Cement." Attendance 14.

University of Cincinnati.—January 19, 1915. Address by Mr. Gregory Brown on "The Use of the Telephone in Train Dispatching and Railway Signaling." Attendance 55.

Colorado State Agricultural College.—January 18, 1915, Electrical Building. Papers: (1) "The Operation of High-Voltage Systems," by Mr. Edmondson; (2) "Hydroelectric Development at Keokuk, Iowa," by Mr. Smith. Attendance 11.

Georgia School of Technology.—December 22, 1914, Electrical Building. Paper: "Incandescent Lighting," by W. M. Rosborough. Attendance 37.

Highland Park College.—January 6, 1915. Main Building. Address by Mr. Clyde Prussman on "Relative Advantages of Direct Current and Alternating Current for Transmission." Attendance 23.

January 20, 1915, Main Building. Paper: "The Power Plant and Dam at Keokuk, Iowa," by E. B. Williams. Attendance 22.

University of Iowa.—January 21, 1915, Physics Hall. Paper: "Some Applications of Electricity in Metallurgy," by A.W. Hixson. Attendance 18.

University of Kansas.—January 25, 1915. Address by Mr. Barnes on "The Motor in the Oil Fields," illustrated with lantern slides. Attendance 30.

State University .of Kentucky.—February 4, 1915, Mechanical Hall. Paper: "Machine Tools and General Motor Applications," by F. H. Herzsch. Attendance 41.

Lafayette College.—January 21, 1915, Pardee Hall. Papers: (1) "Graphic Meters; Their Types and Uses," by Mr. Jefferson; (2) "The Grounded Neutral; When, Why, and How," by P. M. Lee; (3) "Multivoltage D-C. Systems of Control for Machine Tool Drive," by W. J. English. Attendance 22.

University of Michigan.—January 7, 1915, Engineering Building. Stereopticon lecture on "Shawinigan Falls Power House," by Ass't. Prof. T. J. MacKavanagh. Attendance 30.

January 21, 1915, Engineering Building. Illustrated lecture on "The Uses of Electricity in Steel Mills," by F. R. Fishback. Attendance 50.

University of Missouri.—January 11, 1915, Engineering Building. Paper: "Electrical Processes," by L. P. Boll. Attendance 18.

Montana State College.—January 19, 1915, Lyric Theatre. Moving pictures of the Butte, Anaconda and Pacific Railroad electrification and of the works of the General Electric Company. Attendance 156.

North Carolina College of Agricultural and Mechanical Arts.—West Raleigh, N. C. Papers: (1) "Wireless Communication as Applied to Railroad Lines;" (2) "The Edison Nickel-Iron Storage Battery." Attendance 25.

January 26, 1915. Abstract of engineering articles, by Messrs. Jeffers, Robinson and Baker. Attendance 25.

February 9, 1915. Demonstration of the Duddell oscillograph, by Professor Browne. Attendance 28.

Ohio Northern University.—January 27, Hill Memorial. Papers: (1) " Electric Locomotive Design," by H. M. Downing; (2) "Modern Wireless," by W. L. Riggin. Attendance 18.

University of Oklahoma.—January 20, 1915, Engineering Building. Papers: "Electrical Development in 1914," by A. M. Brown; "Rural Electricity," by C. M. Mackey; "Lord Kelvin," by Mr. Freeman. Attendance 17.

University of Pittsburgh.—January 21, 1915, Thaw Hall. Election of officers as follows—chairman, G. W. Flaccus; vice-chairman, H. H. Tinch; Secretary-treasurer, R. C. Zindel. Attendance 16.

Stanford University.—January 24, 1915, Engineering Building. Illustrated address by Mr. F. S. Mulock on "The Big Creek Development of Southern California." Attendance 10.

University of Texas.—January 8, 1915. Papers: (1) "History and Organization of the A. I. E. E., and Suggestions for Conducting the Branch Meetings," by J. M. Bryant; (2) "The Austin Dam," by L. N. Zant. Attendance 17.

University of Virginia.—January 19, 1915, Engineering Building. Election of officers as follows—Chairman, Walter S. Rodman; secretary, Allen W. Wright; executive committee, Walter S. Rodman, Charles H. Chandler, Jr., and Thomas C. Ritchie. Attendance 8.

February 2, 1915, Mechanical Laboratory. Paper: "Developments in the Electrical Field during 1914," by Walter S. Rodman. Attendance 10.

Washington University.—January 14, 1915, Cupples Hall. Paper: "The Watt-Hour Meter," by Mr. Bradshaw. Attendance 32.

West Virginia University.—January 7, 1915, Mechanical Hall. Address on "Some Recent Developments in the Field of Electricity," by Vladimir Karapetoff. Demonstration of electromechanical equipment of Mechanical Hall. Attendance 189.

February 5, 1915, Mechanical Hall. Papers: (1) "The Transcontinental Telephone System," by J. D. Gordon; (2) "The Growth of a Public Utility," by J. D. Gordon. Papers were illustrated by moving pictures. Attendance 118.

Yale University.—January 15, 1915. Paper: "Telephone Engineering," by E. H. Everit. Attendance 130.

Personal

MR. E. M. BREED, who for the past eight years has been district manager of the Canadian Allis-Chalmers Company, Ltd., with headquarters at Vancouver, has been appointed district manager of the Pelton Water Wheel Company. He will continue his headquarters at Vancouver. Previous to his connection with the Canadian Allis-Chalmers Company, Mr. Breed was with the sales force of the Canadian Westinghouse Company at Montreal.

MR. EDUARDO DE A. BRAGA, who has been in this country for more than a year past as special delegate of the Ministry of Agriculture and the Ministry of Public Works of Brazil, sailed for Brazil on February 11. After making his formal report, Mr. Braga will act as the representative in Rio de Janeiro of the United States Purchasing Corporation, Woolworth Building, New York. He will be prepared to make reports on the possibilities of marketing American-made goods, with special attention to electrical equipment.

MR. A. B. SAURMAN, who has been for the past twelve years Pacific coast manager of the Standard Underground Cable Company, has been appointed Southeastern manager of the company (succeeding the late Mr. T. E. Hughes), with headquarters in Philadelphia, and will return East early in the spring. Mr. Saurman has been connected with the company for over 21 years. He will be succeeded as Pacific coast manager by Mr. John P. Bell, who for the past eight years has been located in Pittsburgh as assistant secretary and treasurer of the company.

Obituary

CYRUS FOGG BRACKETT, professor emeritus of physics in Princeton University, died on January 29, 1915, in Princeton. Dr. Brackett was born at

Parsonfield, Maine, June 25, 1833. He was graduated from Bowdoin College in 1859, and four years later received the degree of M. D. From 1863 to 1864 he was instructor of chemistry at Bowdoin, and professor from 1864 to 1873. Subsequently he was professor at Princeton for thirty-five years. Since 1908 he had been professor emeritus. He was a recipient of the honorary degree LL.D. from Lafayette, Bowdoin and Princeton. Dr. Brackett was one of the early members of the Institute, and served as Manager for the term 1886-89.

H. Ward Leonard, the well-known electrical engineer and inventor, founder of the Ward Leonard Electric Company, Fellow of the Institute, died suddenly in the evening of February 18, while he was attending the Institute dinner at the Hotel Astor, in connection with the Midwinter Convention. His wife and sister were with him at the dinner. Mr. Leonard had left the banquet hall, and his death occurred while he was in an anteroom. It was the earnest wish of Mrs. Leonard that no word of the sad news should reach the other guests. In fact the guests, almost without exception, did not learn of Mr. Leonard's death until the next morning.

H. Ward Leonard was born at Cincinnati, Ohio, February 8, 1861. He was graduated from the Massachusetts Institute of Technology in 1883, and in the following year became associated with Thomas A. Edison as one of his staff of four engineers engaged in installing the Edison central station systems. In 1887 Mr. Leonard became general superintendent of the Western Electric Light Company at Chicago, and during the following two years was senior partner of the firm of Leonard and Izard, of Chicago, and in this connection made many important installations of central station and electric railway plants in various parts of the United States. In 1889 the firm was bought out by the parent Edison interests, and Mr. Leonard became general manager of the light and power department of the combined Edison interests for the United States and Canada, with headquarters in New York. In 1891 he resigned to establish his own independent manufacturing business, which is still operating as the Ward Leonard Electric Company, at Bronxville, New York. It was in this year that he completed the invention of his system of motor control, and in 1892 his multiple voltage system. Since then patents had been issued to him on more than one hundred important inventions, a great body of inventive work which is well known to all electrical engineers. In 1903 the Franklin Institute conferred upon Mr. Leonard the John Scott Medal for work in electrical research. He was also awarded gold medals at the Paris Exposition in 1900 and the St. Louis Exposition in 1904.

The Board of Directors, at its meeting on February 19, adopted the following resolutions as an expression of appreciation of Mr. Leonard's services to the Institute:

> "Mr. H. Ward Leonard, an honored Fellow and Life Member, became an Associate on July 12, 1887, since which time he steadfastly maintained his connection and interest in the Institute. He was elected a Manager in 1890, serving for the full term of three years. At the expiration of his term as Manager he was elected a Vice-President, in which office he continued to serve the Institute for the two years from 1893 to 1895. He also served on various committees, and at the time of his death was a member of the Edison Medal Committee. He was transferred to the grade of Fellow on April 9, 1913.
>
> "The Board of Directors recognizes that in the death of Mr. Leonard, the Institute and the engineering profession have sustained a great loss, and it extends its deep sympathy to the members of his family in their bereavement."

Recommended for Transfer, February 15, 1915

The Board of Examiners, at its regular monthly meeting on February 15, 1915, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

Hunt, Fred L., Chief Engineer, Turners Falls Power and Electric Co., Greenfield, Mass.

Pierce, Arthur G., District Engineer, Cutler-Hammer Mfg. Co., Pittsburgh, Pa.

Zogbaum, Ferdinand, Engineer of Maintenance, New York, Westchester & Boston Ry., New York, N. Y.

Transferred to the Grade of Member February 19, 1915

The following Associate was transferred to the grade of Member of the Institute at the meeting of the Board of Directors on February, 1915.

Ruttencutter, A. T., Electrical Engineer, Rio de Janeiro Tramway, Light & Power Co. Ltd., Rio de Janeiro, Brazil.

Members Elected February 19, 1915

Arsem, William C., Chemical Engineer, Research Laboratory, General Electric Co., Schenectady, N. Y.

Emrick, Paul S., Instructor in Electrical Engineering, Purdue University, Lafayette, Ind.

Lawson, James T., Chief Operator, Public Service Electric Co., Broad & Bank Sts., Newark, N. J.

Wilson, Everitt Wyche, General Superintendent, R. W. Hebard & Co. Inc., 117 Ave. B., Panama, R. P.

Associates Elected February 19, 1914

*Adam, Edward N., Melville, Montana.

Armstrong, John W. F., Engineering Assistant, General Construction Dept., Pacific Gas & Electric Co., San Francisco, Cal.

Beil, Eugene H., Manager of Light & Power, Mahoning & Shenango Ry. & Light Co.; res., 33 Williamson Ave., Youngstown, Ohio.

Benz, Carl D., Secretary to General Manager, Pacific Light & Power Corp., 633 Pacific Electric Bldg., Los Angeles, Cal.

*Bosshart, Harry J., Power Station Operator, Pacific Gas & Electric Co., Nevada City, Cal.

*Bradley, Harold H., Electrical Operator, Kern River Substation, Pacific Light & Power Corp.; res., 210 So. Flower St., Los Angeles, Cal.

Brink, Harrison S., Assistant Electrical Engineer, Signal Service, Panama Canal, Balboa Heights, C. Z.

Burr, Gordon A., Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 419 Biddle Ave., Wilkinsburg, Pa.

Butlin, Charles A., Telegraph Engineer; res., Hotel America, 102 E. 15th St., New York, N. Y.

*Case, Charles D., Instructor in Electrical Engineering, De Pauw University; res., 1024 Belden Ave., Chicago, Ill.

*Chaney, Leonard P., Chief Engineer, Texas City Transportation Co., Power House, Texas City, Tex.

Choksey, Khurshed P., Superintendent of Sub-Stations, Calcutta Electric Supply Corp.; res., 96 Princess St., Calcutta, India.

Clark, J. Rowley, Construction Superintendent, James J. Phillips Co., Rochester; res., Irondequoit, N. Y.

Coney, A. E., Superintendent, Meter Dept., City Electric Co., San Francisco; res., 2028 Clinton Ave., Alameda, Cal.

Couper, Harold W., Engineering Dept., Wagner Electric Mfg. Co.; res., 3857a De Tonty St., St. Louis, Mo.

Covey, G. Stanley, Electrical Mechanic, Washington Water Power Co., Spokane, Wash.

Coward, O. L., Sales Agent, General Electric Co., 609 Colman Bldg., Seattle, Wash.

Crockett, Albert S., Electrical Engineering Dept., General Electric Co.; res., 24 Baker St., Lynn, Mass.

CROSBY, GEORGE L., Sales Manager, Roller-Smith Co., 203 Broadway, New York, N. Y.

*DAVID, BRUCE WILLIAM, Electrical Engineer, Lincoln Electric Co.; res., 1628 E. 70th St., Cleveland, O.

DAVIS, ERNEST W., Electrical Engineer, Simplex Wire & Cable Co., Cambridge, Mass.

*DEANS, WILLIAM, JR., Instructor, Electrical Engineering, Cornell University; res., 420 Eddy St., Ithaca, N. Y.

DE LA ROSA, JOHN C., Student, New York Electrical School; res., 133 W. 132nd St., New York, N. Y.

EDGECOMB, HENRY R., Research Engineer, Westinghouse Electrical & Mfg. Co., East Pittsburgh, Pa.

EICHELBERGER, CHESTER G., Commercial Engineer, Union Gas and Electric Co., Cincinnati, Ohio.

EILERS, HENRY, Junior Electrical Engineer, Public Service Commission, 1st District, 154 Nassau St., New York, N. Y.

*EULER, HENRY J., Experimental Testing, Cutler-Hammer Co., 144th St. & So. Boulevard; res., 383 East 136th St., New York, N. Y.

*FICKEL, GLENN R., Engineer, Service Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

FITZ, ARTHUR EDWARD, Chief Electrician, Draycott Mills Co., New Hartford, Conn.

FUJITA, TSUNESADA, Technical Adviser, Han-Yeh-Ping Steel & Coal Co., Shanghai, China.

GARDINER, GLEN K., Telephone Engineer, Pacific Telephone and Telegraph Co., 1103 Telephone Bldg., Portland, Ore.

GEIGER, JAMES M., Operator, Panama Canal, Gatun, C. Z.

GHOSE, MANORANJAN, Standardizing Laboratory, General Electric Co., Schenectady, N. Y.

*GRAHAM, EDWARD B., Commercial Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

GREENLEAF, MYNDRET C., Solicitor, Monroe Gas, Light & Fuel Co., Monroe, Mich.

*GRISWOLD, LESTER E., Illuminating Engineer, Store Lighting Dept., Macbeth-Evans Glass Co., 828 Wabash Bldg., Pittsburgh, Pa.

*GROWER, ROY WILLIAM, Assistant Superintendent, Bureau of Gas and Electricity; res., 229 Merriman Ave., Syracuse, N. Y.

*GRUEN, E. C., Assistant Professor, Department of Drawing, Georgia School of Technology, Atlanta, Ga.

*GUILLOU, ALFRED V., Sales Engineer, Pacific Light & Power Corp.; res., 1001 S. Burlington Ave., Los Angeles, Cal.

*HARDEN, WILLIAM H., Engineering Dept., American Telephone & Telegraph Co., New York; res., 1121 Bedford Ave., Brooklyn, N. Y.

*HEALD, WALLACE S., Electrical Engineer, Mississippi River Power Co., Keokuk, Iowa.

HEISING, RAYMOND A., Research Laboratory, Western Electric Co., 463 West St., New York, N. Y.

HERRMAN, HENRY, Manager, Metals Dept., Ft. Wayne Electric Works of General Electric Co., Ft. Wayne, Ind.

HILL, WILLIAM C., Secretary, Benolite Co., 331 Fourth Ave., Pittsburgh, Pa.

HOSFELD, DAVID C., Plant Supervisor, Diamond State Telephone Co., 6th & Shipley Sts., Wilmington, Del.

HOVLAND, HENRY, Telephone Engineer, Western Electric Co., New York, N. Y.; res.; 50 S. 20th St., E. Orange, N. J.

HOWE, JESSE W., Electrician Foreman, Iowa Railway & Light Co., Cedar Rapids; res., 405 Marshall St., Boone, Iowa.

ISRAEL, LESTER L., Expert Radio Aid, United States Navy; res., 106 W. 69th St., New York, N. Y.

JOHNSON, ARTHUR, Draftsman, Engg. Drawing Office, General Electric Co., Witton; res., 22 Dolman Rd., Aston Manor, Birmingham, England.

*KELLER, LLOYD MARLEY, Engineering Dept., Rochester Railway & Light Co., 34 Clinton Ave. N., Rochester, N. Y.

Leipoldt, Ewald V., Electrical Engineer, Chile Exploration Co., 165 Broadway; res., 202 W. 92nd St., New York, N.Y.

Lennon, Robert J., Jr., Electrician, Rochester Railway & Light Co.; res., 386 Lake View Pk., Rochester, N. Y.

***Leonard, Lynn** R., Instructor in Electrical Engineering, University of Colorado; res., 1624 Hill St., Boulder, Colo.

***Magee, John** W., Sales Apprentice, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 431 Rebecca Ave., Wilkinsburg, Pa.

***Manley, Rowland**, Substation Operator, Sanitary District of Chicago; res., 3820 Cornelia Ave., Chicago, Ill.

Maurice, R., Manager and Electrical Superintendent, Selkirk Municipal Light & Power Dept., Selkirk, Man.

***Melcon, Sisag** V., Electrician, Phoenix Construction Co., Phoenix, Idaho.

***Melcon, Zenope** P., Power House Operator, Pacific Light & Power Corp., Power House No. 2, Big Creek, Cal.

Melillo, Rogue, Student, New York Electrical School, 39 W. 17th St., New York, N. Y.

Meyer, John W., Engineer, Commercial Dept., Philadelphia Electric Co.; res., 6420 Woodland Ave., Philadelphia, Pa.

Miller, Harry N., Secretary, McNaughton-McKay Electric Co., 70 Jefferson Ave., Detroit, Mich.

Moore, Leonard J., Chief Load Dispatcher, San Joaquin Light & Power Corp.; res., 1015 " O " St., Fresno, Cal.

***McBride, Francis** R., Student, University of Oregon; res., 487 E. 23rd St. N., Portland, Ore.

McDonald, George R., Line and Construction Foreman, Sierra and San Francisco Power Co.; res., 184 Clinton Park, San Francisco, Cal.

McKenzie, D. A., Meter Inspector, Hydro-Electric Power Commission; res., 1609 Queen St. West, Toronto, Ont.

***McNair, James** S., Washington Water Power Co.; res., 234 Park Place, Spokane, Wash.

Nelson, Norman C., Overhead Distribution Engineer, City Light Dept., Prefontaine Bldg., Seattle, Wash.

***O'Connell, John** J. F., Adirondack Electric Power Corporation, Glens Falls; res., 172 4th St., Troy, N. Y.

Olds, Robert Russell, Superintendent, Electrical Dept., Belding Bros, & Co., Belding, Mich.

Pearl, Allen S., Secy. and Treas., Delta-Star Electric Co., Chicago; res., 1516 S. Sixth Ave., Maywood, Ill.

Ransom, Lewis Lee, Asst. Supt., Construction Dept., The Maintenance Co.; res., 530 W. 166th St., New York, N. Y.

Ripley, Charles S., District Manager, Roller-Smith Co., 711 Williamson Bldg., Cleveland, Ohio.

***Rock, Chalmers** R., Electrical Superintendent, Stow Manufacturing Co., Binghamton, N. Y.

***Rogers, Asa Leroy**, Junior Engineer, George F. Hardy, 309 Broadway, New York, N. Y.

Rooker, George N., Manager, Northern Idaho & Montana Power Co., Standpoint, Idaho.

Rosch, Samuel J., Cable Tester, Safety Insulated Wire & Cable Co., Bayonne, N. J.

Ruff, Adolph G., Electrical Draughtsman, Ballinger & Perrot; res., 1327 Porter St., Philadelphia, Pa.

Sampson, Edgar R., Designing Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 1028 South Ave., Wilkinsburg, Pa.

***Schenck, Chester**, Switchboard Attendant, Milwaukee Electric Railway & Light Co.; res., 146 Martin St., Milwaukee, Wis.

***Schumann, John** H., Edison Illuminating Co. of Detroit; res., 451 Garland Ave., Detroit, Mich.

***Seltzer, David**, Electrical Tester, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

***Service, Jerry Hall**, Instructor, State High School, Stephen, Minn.

*SHEPPARD, HARRY S., Instructor in Electrical Engineering, University of Michigan, 109 New Engg. Bldg., Ann Arbor, Mich.

SHIRE, WILLIAM J., Salesman, Roller-Smith Co., New York; res., 1216 Vine St., Richmond Hill, N. Y.

SHUEY, OLYN R., Electrical Engineer, West Virginia Pulp and Paper Co., Piedmont, W. Va.

*SIMON, RICHARD J., Engineer, Transformer Div., Westinghouse Elec. & Mfg. Co.; res., 1906 Lowrie St., Pittsburgh, Pa.

SLINGMAN, T. D., District Manager, Chicago Pneumatic Tool Co., 2nd and Amsterdam Ave., Detroit, Mich.

*SMITH, CLINTON D., Traffic Investigator, Public Service Railway Co., Newark; res., 120 Chestnut St., Kearny, N. J.

*SMITH, RUSSEL H., General Power Tester, Penn Central Light & Power Co.; res., 2003 8th Ave., Altoona, Pa.

SNOW, WILLIAM JAMES, Electrical Operator, Interborough Rapid Transit Co., 74th St. Power Station, New York; res., Crestwood, Yonkers, N.Y.

*SOENGEN, GERALD W., Electrical Engineer and Contractor, Kirkwood, Mo.

STAUFFACHER, EDWIN R., Asst. Power Engineer, Southern California Edison Co., Los Angeles; res., 421 Orange Grove Ave., Glendale, Cal.

STEPHENS, ROY E., Chief Electrician, FollansbeeBros.Co.,Follansbee,W.Va.

*STEVENS, PAUL S., Statistician, Union Electric Light & Power Co.; res., 5269 Vernon Ave., St. Louis, Mo.

*STICHT, ALFRED E. J., Student, Rensselaer Polytechnic Institute, Troy, N. Y.

*STORY, ROLAND A., Telephone Engineer, British Columbia Telephone Co., Ltd.; res., 325 13th Ave. W., Vancouver, B. C.

TANAKA, TATSUO, Chief Engineer, Direct Current Designing Dept., Shibaura Engineering Works, Kanasugi, Shiba, Tokyo, Japan.

THOMAS, W. R., Superintendent, Wenatchee Valley Gas & Electric Co., Wenatchee, Wash.

TILLOTSON, CHARLES C., Chief Draftsman, Montana Power Co., Electric Bldg., Butte, Mont.

*WHIPPLE, CARL ARTHUR, Load Dispatcher, Power Dept., Texas Power & Light Co., Hillsboro, Texas.

*WHITAKER, DWIGHT A., Assistant System Operator, Public Service Co. of Northern Illinois, Evanston, Ill.

WHITE, WILLIAM COLLINS, Estimator, Cumberland Telephone and Telegraph Co., Memphis, Tenn.

WIDDOWS, RICHARD G., District Manager, Electric Controller & Mfg. Co., 50 Church St., New York, N. Y.

WILKE, RUDOLPH C., Electrician, Wells Power Co., Milwaukee, Wis.

WILSON, ALEXANDER, 3rd, Inspector (Construction), Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

*WYATT, FRANCIS DALE, Engineer, Doherty Operating Co., 60 Wall St., New York, N. Y.; res., Columbus, Ohio.

YAMAWAKI, MASAYOSHI, Electrical Engineer, Kinugawa Hydro-Electric Power Co., Marunouchi, Tokyo, Japan.

ZIMA, LUDWIG A., Assistant Engineer, New York Railways Co., and Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

Total 108

*Former enrolled Students.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1915.

Amberg, E. J., New Haven, Conn.
Anderson, H. O., Conners Creek, Mich.
Baker, G. R., Schenectady, N. Y.

Bitzer, O. F., New Haven, Conn.
Brandt, W. Van C., Pittsburgh, Pa.
Brooke, G. A., Jr., Philadelphia, Pa.
Champagne, L. J., Los Angeles, Cal.
Champion, C. H., New York, N. Y.
Chung, D. M., Shanghai, China.
Clark, W. A., E. Pittsburgh, Pa.
Cowdrey, W. L., Superior, Wyo.
Cunningham, W. J., Calgary, Alta.
Curling, H. W., Toronto, Ont.
Czarnecki, F. C., San Francisco, Cal.
Dawson, H. L. (Member), Chicago, Ill.
Dichman, E., Mare Island, Cal.
Dobson, J. V., E. Pittsburgh, Pa.
Edwards, G. L., Stayton, Ore.
Einstein, A. C. (Fellow), St. Louis, Mo.
Farnham, W. E., New York, N. Y.
Floyd, F. T., E. Pittsburgh, Pa.
Flynn, A. A., Gold Hill, Ore.
Frost, L. E., E. Pittsburgh, Pa.
Gaffey, J. J., Boston, Mass.
Gardner, F. Q. C., Fort Totten, N. Y.
Grierson, C. I., Edmonton, Alta.
Guy, G. L., Winnipeg, Man.
Hacker, G., Vienna, Austria.
Hamilton, R. F., Manchester, England.
Harris, J. A., Toronto, Ontario.
Harrison, W. T., Portland, Ore.
Harvey, H. G., Chicago, Ill.
Hile, C. H. (Member), Boston, Mass.
Hirt, W. A., Detroit, Mich.
Hoot, D. W., Schenectady, N. Y.
Huff, J., Olmstead, Utah.
Hull, B. D., St. Louis, Mo.
Irey, G. W., St. Joseph, Mo.
Jefferson, R. D., Boise, Idaho.
Johnson, M. J., Waterbury, Conn.
Kane, J. J. (Member), Milwaukee, Wis.
Lee, B. F., Niagara Falls, N. Y.
Lloyd, W. E., Jr., Martins Creek, Pa.
Lunsford, J. B., Ampere, N. J.
Mabbs, J. K., Chicago, Ill.
Mackenzie, A. M., Guelph, Ont.
Moore, W. D., Portland, Ore.
Morrow, A., Richmond, Cal.
O'Neill, T. F., New Haven, Conn.
Peart, J. W., London, Ontario.
Pollard, J. F., Drum, Cal.
Posa, E., Barcelona, Spain.
Ramsay, L. M., Schenectady, N. Y.
Rese, W. F., Weirton, W. Va.
Riddell, J. L., Philadelphia, Pa.
Smith, L., Rumford, Maine.
Spahr, C. W., Racine, Wis.
Stephenson, J., Columbia, S. C.
Thomson, S. E., Niagara Falls, Ont.
Uptegraff, R. E., Pittsburgh, Pa.
Vanderhoof, C. N., Newark, N. J.
Wier, H.B. (Member), New York, N. Y.
Wilson, J., Cambridge, Mass.
Winston, W. O., Jr., Minneapolis, Minn.
Young, J. A., Atlanta, Ga.
Total, 65.

Students Enrolled February 19, 1915

7105 Bond, J. M., Worcester Poly. Inst.
7106 Hoyert, J.H., Univ. of Pittsburgh.
7107 Walz, A. J., Purdue University.
7108 Hildebrand, E. W., Lewis Inst.
7109 McGregor, A. J., Cooper Union.
7110 Zant, L. N., Univ. of Texas.
7111 Smith, L. M., Univ. of Alabama.
7112 Webber, L. G., Tufts College.
7113 Shulze, G. F., Univ. of Missouri.
7114 Davis, G. E., Okla. A. & M. Coll.
7115 Fisher, J. M., Okla. A. & M. Coll.
7116 Schaefer, P., Okla. A. & M. Coll.
7117 Lovell, C. M., Okla. A. & M. Coll.
7118 Peck, H. L., Okla. A. & M. Coll.
7119 Junkins,R.D.,Carnegie Inst.Tech.
7120 Keiser, W., Bucknell University.
7121 Hott, O. J., Univ. of Oklahoma.
7122 Hott, W. M., Univ. of Oklahoma.
7123 de Macedo, A., Univ. of Penna.
7124 Ferguson, E. L., Washington State College.
7125 Mensch, S. R., Bucknell Univ.
7126 Ernst, M., Columbia University.
7127 Heisler, S. E., Lehigh Univ.
7128 Reace, W. T., Univ. of Illinois.
7129 Palmer, R. T., Univ. of Alabama.
7130 Felt, W. L., Univ. of Oklahoma.
7131 Pawnell, A. M., Univ. of Okla.
7132 Oster, C. C., Univ. of Oklahoma.
7133 Malott, E. O., Purdue University.
7134 Cravens, W. H., Rensselaer Poly. Institute.
7135 Pope, L. A., Univ. of Illinois.
7136 Ficke, W. M., Tufts College.
7137 Glasier, R. C., Univ. of Michigan.
7138 Wagner, L. R., Univ. of Michigan.
7139 Moore, C. W., Univ. of Michigan.
7140 Hall, W. C., Univ. of Michigan.
7141 Edlund, L. L., Armour Inst. Tech.
7142 Jordan, L. J., Univ. of Texas.

7143 Hardey, F. J., Jr., Univ. of Texas.
7144 Miller, W. J., Univ. of Texas.
7145 Linscott, H.D., Kans. St. Agri. Coll.
7146 Rusch, H. W., Univ. of Wisconsin.
7147 Nagahama, S., Harvard Univ.
7148 Shipman, C. F., Colo. Agri. Coll.
7149 Waite, R. A., Univ. of California.
7150 Swanson, A. J., Colo. Agri. Coll.
7151 von Lindeman, C., Jr., Highland Park Coll.
7152 MacCalla, P. S., Univ. of Penna.
7153 Lovell, W. V., Ga. Sch. Tech.
7154 Metcalf, J. L., Ga. Sch. Tech.
7155 Glover, R. P., Ga. Sch. Tech.
7156 Hughes, E. L., Washington Univ.
7157 Franklin, C. O., Univ. of Pitts.
7158 Keck, R. M., Univ. of Texas.
7159 Oster, E. A., Univ. of Cincinnati.
7160 Hada, T., Harvard University.
7161 Paxton, G. L., Colo. Agri. Coll.
7162 Mackey, C. M., Univ. of Okla.
7163 Hawkins, R. D., Worcester Poly. Inst.
7164 Yates, C. C., Harvard University.
7165 Johnston, W. M., Univ. of Ala.
7166 Clarkson, W. B., Harvard Univ.
7167 Donnell, P. S., Harvard Univ.
7168 Whipple, C. C., Worcester Poly. Inst.
7169 Johnson, R. T., Univ. of Pitts.
7170 Gleason, D.T., Carnegie Inst. Tech.
7171 Munyan, E. A., Univ. of Penna.
7172 Levin, J. M., Drexel Institute.
7173 White, W. R., Drexel Institute.
7174 Trate, G. M., Drexel Institute.
7175 Apfelbaum, E., Drexel Institute.
7176 Vianna, S. P., Drexel Institute.
7177 Oliphant, A. C., Drexel Institute.
7178 VanInwegen, L.C., Lafayette Coll.
7179 Brown, A. M., Univ. of Okla.
7180 Woodson, J.C., Okla. A.&M. Coll.
7181 Parsons, A.W., Okla. A. & M.Coll.
7182 Notson, F. C., Okla. A.&M. Coll.
7183 Cobb, C. C., Okla. A. & M. Coll.
7184 McKenney, M.R., Univ. of Maine.
7185 Banks, W. M., Univ. of Pitts.
7186 Jeanne, P., Colorado College.
7187 Cardoso, A. de M., Highland Park Coll.
7188 Woodruff, H. L., Highland Park College.
7189 Hantman, B., Carnegie Inst. Tech.
7190 Heffner, O.C., Carnegie Inst. Tech.
7191 vonSothen, C.E.H., Columbia Univ.
7192 Steiner, C. R., Syracuse Univ.
7193 Nash. DeL. D., Syracuse Univ.
7194 Woodard, G. E., Syracuse Univ.
7195 Fulmer, L. S., Syracuse Univ.
7196 Stevens, W. R., Syracuse Univ.
7197 Abreu, C. S., Syracuse Univ.
7198 Daly, C. J., Syracuse Univ.
7199 Woodruff, L. L., Syracuse Univ.
7200 Keefer, W. D., Syracuse Univ.
7201 Shibuta, I., Syracuse Univ.
7202 Silverman, J., Syracuse Univ.
7203 Kuehn, M. H., Syracuse Univ.
7204 Seiter, K. W., Wash. St. Coll.
7205 Sanders, H. M., Bucknell Univ.
7206 Watson, D.J., Clemson A.&M.Coll.
7207 Iler, C. B., Clemson A.&M. Coll.
7208 Beymer, O.H., Clemson A.&M.Coll.
7209 DuVernet, E. P., Clemson A.& M. College.
7210 Reid, E. A., Univ. of Illinois.
7211 Hagemann, E. C., Bucknell Univ.
7212 Webster, J. C., Univ. of Pitts.
7213 Miller, F. H., Univ. of Kansas.
Total 109.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than 50 words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Vacancies

V-58. Opportunity for consulting engineer of broad training to cooperate with firm of industrial engineers requiring frequent advice in electrical matters. Joint occupancy of present established office preferred.

The United States Civil Service Commission announces an open competitive examination for sub-inspector, electrical, for men only, on April 7, 1915, to be held at numerous places in the U. S. From the register of eligibles resulting from this examination certification will be made to fill a vacancy in this position at $4.16 per diem, in the office of Inspector of Engineering Material, U. S. Navy, Pittsburgh, Pa., and vacancies in positions requiring similar qualifications as they may occur in any U. S. navy yard or naval establishment, at entrance salaries ranging from $3.60 to $5.04 per diem, unless it is found to be in the interest of the service to fill any vacancy by reinstatement, transfer, or promotion. In filling vacancies in navy yards and other naval establishments, preference in certification will be given to eligibles residing in the vicinity of the place at which the vacancy occurs.

The duties of the position cover the shop inspection and testing of all types of generators, transformers, motors, motor-generators, up to 300 kw. capacity, together with their controlling apparatus, and the appointee must be capable of making all calculations and deductions connected therewith. The work of the sub-inspector will require travel and temporary location at the various manufacturing plants where contracts for the Navy Department are being carried out.

Persons who meet the requirements and desire this examination should at once apply for the circular announcing this examination (Form No. 213, issued February 13, 1915) and Form No. 1312, stating the title of the examination for which the form is desired, to the U. S. Civil Service Commission, Washington, D. C.

Men Available

203. Electrical Engineer. Graduate (1914) University of Michigan. Desires position in electrical line, preferably in illuminating or manufacturing field. Some experience as machinist and draftsman. Since graduation employed as operator in power plant.

204. Electrical Engineer. Technical education; four years' experience in telephone construction and repair; two years' d-c. and a-c. motor manufacturing, testing and experimental work such as testing automobile starters and lighters. Now employed.

205. Electrical Engineer. Mem. A. I.E.E., I.E.S., S.P.E.E. Degrees B. S.E.E., E.E.; 28 years old. Designing, commercial, industrial and educational experience; desires to specialize in some line. Willing to start at low salary in a permanent position permitting of advancement. Now employed.

206. Operating Engineer. Technical graduate. Thirteen years' experience in operation and management of power plants; transmission line and distribution systems for power, lighting and railways. A good organizer, energetic, and take well with the public. Will go anywhere on short notice.

207. Electrical Engineer. Technical graduate; six years' experience with large light and power companies, including plant, meter, and instrument testing and investigating; also industrial and commercial applications of electric power. Willing to go abroad.

208. Electrical Engineer. Age 24; 1913 graduate. Eighteen months General Electric test. Would like position in or near New York City. Could arrange for interview.

209. Electrical Engineer. Mass. Inst. Tech. 1908. Single, age 30. One year in United States and five years' ex-

perience in Porto Rico and Cuba in operation and administration of small public utilities, street railway, lighting, power and water service, steam and combined hydraulic power stations. Speak Spanish. Willing to go anywhere.

210. Electrical Engineer desires a position with good chances for the future. Technical graduate; single; 28 years old; at present employed. Experience embraces line work (both city and transmission), station operation, station installation, and office work.

211. Electrical Engineer. Technical graduate; one year shop work; five years with railway and light company. Well informed on switchboard work, meter work, line construction. Desires permanent position as chief electrician or superintendent in charge of small plant.

212. Mechanical-Electrical Engineer; technical graduate. Construction, operating, and executive experience in large water, gas and electric utilities; also investigation, rate, valuation, auditing, and cost analysis work as principal assistant to consulting engineers and on staff of large utilities. Desires association with company, consulting engineer, investigator, or commission.

213. Electrical Engineer. Qualified to install and operate hydroelectric plants, substations, industrial power installations. Good at doctoring sick plants. Experienced in the adaptation of electricity to mines and mills. Age 31; married. No objection to foreign service.

214. Electrical Engineer. Graduate of University of Wisconsin. Thirteen years' experience contracting for interior wiring systems for light and power; also selling supplies and apparatus. Desires position with consulting, contracting, or selling concern.

215. Technical graduate (1914) desires position in an electrical engineering department or consulting engineering office. At present employed as assistant in electrical laboratory. Some experience in central station office work. Present employment expires about middle of June. Will consider foreign service.

216. Electrical-Mechanical Engineer. Age 30; married. Past five years superintendent and manager of electric light and steam heat company, directing construction, operation and maintenance, as well as business of plant. Increased business over 400 per cent. Desires position in any phase of central station work.

217. Standardization can be efficiently done during periods of business depression. An electrical engineer with seasoned judgment in such matters, good technical education and comprehensive experience in the manufacture of electrical apparatus, is seeking new fields needing his efforts. Age 36. Temperate. Persistent. Happily married.

218. Electrical Engineer. Practical and teaching experience. Desires position as instructor in electrical engineering.

219. Sales Engineer. Technical education; five years' sales experience on electrical and mechanical (elevating and conveying) machinery; eight years on electrical and mechanical design; four years on hydroelectric installation, test, and operation. At present employed as sales engineer; can leave on one month's notice.

220. Electrical Engineer. Technical education; General Electric test. Twelve years' experience electrical construction, operation and repair of electrical apparatus connected with large industrial plants. Past five years with large lumber company installing electrical equipment of complete plant and in charge of all construction and repair work. Desires position with large lumber company, but open to any good offer.

221. An experienced and successful teacher of electrical engineering is available for school year beginning September 1. Five years' experience in design, construction and operation of power plants; four years' teaching experience in large university. One book largely used as a text in engineering schools; another will be issued this spring.

222. Graduate Engineer. Married; age 38. Seventeen years' experience in design, building, operation and management of power plants (steam and hydroelectric), substations, distributing systems (high- and low-tension), industrial plants and equipments; safety and efficiency engineering. Competent executive and successful in handling employes.

223. Electrical Engineer. Single; age 27. Has had broad testing experience and is familiar with central station production and distribution. Desires managership of small light and power company or production work in connection with larger central station. Managing small plant at present; de-

sires change. New York or adjacent states preferred.

224. Technical Graduate, thirteen years' practical experience in testing, estimating, specification work, power plant design, construction and maintenance, general and special engineering, etc., with large railway, light, power and engineering corporations in States and Canada. Is willing to go anywhere, North or South America. Salary not of first importance.

225. Electrical Engineer. Technical graduate; age 34. Experience with electrical manufacturing company, design of stations and transmission lines, and central station operation as assistant superintendent of large system. Familiar with appraisal of electric properties and rate research. Desires position with consulting engineering firm or operating company as commercial power engineer.

226. Electrical Engineer. Technical graduate; age 32. Ten years' experience in estimating, design and construction of large power developments; also experienced in appraisals. At present employed, but can leave on short notice. Will consider any part of the United States. Mem. A. I. E. E.

227. District Sales Representative and Engineer. Electrical and Mechanical Engineer—technical training—twenty years' practical experience as engineer, salesman and manager. Familiar with commercial and industrial engineering. Ten years branch manager large electrical manufacturing company. Wide acquaintance with men of large affairs. Have established record. Member A. I. E. E.

228. Electrical and Mechanical Engineer. 25 years' experience with electric railway, lighting and construction companies. Will be available about April 1. Temporary or permanent engagement anywhere in U. S., on construction, operation or consulting engineering, steam or electrical, or appraisal work, with electric railway, lighting or industrial company. Member A. I. E. E.

229. Electrical and Mechanical Engineer. 14 years' experience in U. S. and Canada, designing and manufacturing d-c. and a-c. machinery. Has acted in both advisory and supervising capacities.

230. Manager-Engineer. Fellow A. I. E. E., Member A. S. M. E. 18 years' experience in construction design and operation of hydroelectric, high-voltage systems. Specialist in hydroelectric power plant management and construction, mechanical, civil and electrical engineering; broad experience, economy and improvement in operation. Speak Spanish and English. Prefer Latin-American or foreign engagement.

231. Superintendent and Engineer. Twenty years' experience in operation and construction with large central station system; especially successful in producing economical results; desires engagement as manager or superintendent of large company. Good salary expected. Services available within thirty days.

232. Electrical Engineer. Graduate; single; age 23. Desires position with electric power company in South America, preferably as meter man. More than two years test and design with General Electric Co., and at present employed in meter department of a southern power company.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Institute of Electrical Engineers. Year Book 1915. New York, 1915. (Gift.)

Automatic Telephony. By A. B. Smith and W. L. Campbell. New York, 1914. (Purchase.)

Bureau des Longitudes. Annuaire, 1915. Paris Gauthier-Villars et Cie, 1915. (Gift of publisher.)

Depreciation and Rate Control. By A. A. Young. (Reprinted from the Quarterly Journal of Economics, Aug. 1914.) (Gift of R. E. Livingston.)

Electrical Trades' Directory and Handbook for 1913. London, 1913. (Gift of National Electric Light Association.)

Die Elektrischen Erscheinungen in Metallischen Leitern. By K. Baedeker. (Die Wissenschaft, pt. 35.) Braunschweig, 1911. (Purchase.)

Elektrizität in Brauereien. By W. Dräsel. Leipzig, 1914. (Purchase.)

Elektromagnetische Theorie der Strahlung. Ed. 2. By M. Abraham. (Theorie der Elektrizität, Ed. II.) Leipzig, 1908. (Purchase.)

Graphical Determination of Sags and Stresses for Overhead Line Construction. By Guido Semenza and Marco Semenza, translated from the Italian by C. O. Mailloux. New York, 1915. (Purchase.)

Grundzüge der Elektrotechnik. By H. Görges. Leipzig, 1913. (Purchase.)

India Rubber, Gutta Percha and Electrical Trades' Diary and Year Book, 1915. London, 1915. (Gift of India Rubber Journal.)

International Catalogue of Scientific Literature. 11th Annual Issue. D—Chemistry. London, 1914. (Gift of E. D. Adams.)

——12th Annual Issue. B—Mechanics. London, 1914. (Gift of E. D. Adams.)

Jahrbuch der Elektrotechnik. II Jahrgang, 1913. By Karl Strecker. Munchen, 1914. (Purchase.)

Laboratories Conducted by the City of New York, upon samples taken from deliveries of materials and supplies. Monthly Bulletin of Tests. October 1914. (Gift of Board of Estimate and Apportionment, City of New York.)

Landolt-Börnstein Physikalisch-Chemische Tabellen. Ed. 4. Berlin, 1912. (Purchase.)

Royal Society of London. Philosophical Transactions. Ser. B. vol. 205. London, 1914. (Gift of E. D. Adams.)

Standard Wiring for Electric Light and Power, as adopted by the Fire Underwriters of the United States. By H. C. Cushing, Jr. New York, published by the author, Pulitzer Bldg., 1915. (Gift of author.) Price, $1.00.

This is the twenty-first annual issue of this pocket book, prepared by the author with the co-operation of the National Electric Light Association Committee on Wiring Existing Buildings, and the Society for Electrical Development.

W. P. C.

Theoretische und Praktische Einführung in die Allgemeine Elektrotechnik. By S. Herzog. Stuttgart, 1914. (Purchase.)

Universal Safety Standards. Ed. 2. By Carl M. Hansen. New York, Universal Safety Standards Publishing Co., 1914. (Gift of Publishers.) Price, $3.00.

The first of a series of handbooks compiled by Mr. Hansen under the auspices of the Workmen's Compensation Service Bureau of New York. It is devoted to the safeguarding of machine shops, not the "why" of safeguarding, but the how. Safety devices are not only described, but illustrated by numerous plates, the safeguarding appliance being shown in the safety color, green. Safety appliances for the foundry are also shown.

The great interest in these appliances, due partly to humanitarian considerations and partly to workmen's compensation legislation, is reflected in the great number of appliances pictured and described.

W. P. C.

Water Power Bill. Hearing before the Committee on Public Lands United States Senate, 63d Congress, 3d session. Washington, 1915. (Gift of U. S. Senate.)

TRADE CATALOGUES

Allgemeine Elektricitäts Gesellschaft, Elektrisch Betriebene hauptschacht Fördermaschinen. 97 pp.

Archbold-Brady Co. Syracuse, N. Y. Steel transmission structures and catenary bridges. 32 pp.

Century Electric Co. St. Louis, Mo. Single phase motors.

Delta-Star Electric Co. Chicago, Ill. Bull. no. 15. "Unit Type" high tension indoor equipment. Jan. 1915.

——No. 20. High capacity outdoor substation, high voltage equipment etc. Jan. 1915.

De Laval Steam Turbine Co. Trenton, N. J. Catalogue "B," De Laval high efficiency centrifugal pumps, 1914.

Electric Storage Battery Co. Philadelphia, Pa. The "Exide" battery, type LX for lighting and ignition service. Jan. 1915.

——"Ironclad Exide" batteries, what owners say about,

General Electric Co. Schenectady, N. Y. Bulletin No. 44004. Railway line material for direct suspension. Nov. 1914.

——Bull. 3328. G. E. Electric Fans. 19 pp.

——Bull. 3333. Multiple mercury arc rectifiers. Jan. 1915.

Ohio Brass Co. Mansfield, O. O-B Bulletin. Nov.-Dec. 1914.

Pacific Flush-Tank Co. Chicago—New York. Catalog No. 17. Automatic Sewage Ejectors 1914.

Seabury, Chas. L. & Co. New York City. Catalog No. 10. Seabury safety water tube boilers.

The Cutter Co. Philadelphia, Pa. When a fuse blows. 1915.

Westinghouse Machine Co. East Pittsburgh, Pa. WM 513. Westinghouse Roney stokers. Dec. 1914.

National Lamp Works of General Electric Co. Cleveland, Ohio. Bull. 15A. Engineering features of electric sign lighting. Feb. 1915.

Holophane Works of General Electric Co. Cleveland Ohio. Catalog No. 302. Ivanhoe metal reflectors and fittings for multiple mazda lamps. 32 pp. 1915.

——No. 312. Ivanhoe counterline metal reflectors "C" line fixtures. 23 pp. 1915.

——No. 711. Holophane and opal reflectors and fittings, for commercial lighting. 64 pp. 1915.

——Holophane Hunchman. Jan. 1915.

E. S. Lincoln, Inc. Waltham, Mass. Lincoln electrical laboratories. 16pp.

UNITED ENGINEERING SOCIETY

Bibliographie der fremdsprachigen Zeitschrieftenliteratur. Band IX, 1913. By F. Dietrich. Leipzig, 1914. (Purchase.)

Clark Stabilizer, description. (Gift of M. E. Clark.)

Engineering Index, 1914. N. Y. 1915. (Purchase.)

Geological and Statistical map of Brazil. n.d. (Gift of Consul General of Brazil.)

Handbuch des Wasserbaues. vols. 1-2. By Hubert Engels. Leipzig Berlin, 1914. (Purchase.)

International Railroad Master Blacksmiths' Association. Report of the Proceedings of 22d Annual Convention, 1914. Lima, 1914. (Gift of Association.)

OFFICERS AND BOARD OF DIRECTORS, 1914-1915

PRESIDENT.

(Term expires July 31, 1915.)

PAUL M. LINCOLN.

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1915.)	(Term expires July 31, 1916.)
RALPH D. MERSHON.	C. O. MAILLOUX.

VICE-PRESIDENTS.

(Term expires July 31, 1915.)	(Term expires July 31, 1916.)
J. A. LIGHTHIPE.	F. S. HUNTING.
H. H. BARNES, JR.	N. W. STORER.
C. E. SCRIBNER.	FARLEY OSGOOD.

MANAGERS.

(Term expires July 31, 1915.)	(Term expires July 31, 1916.)	(Term expires July 31, 1917.)
COMFORT A. ADAMS.	H. A. LARDNER.	FREDERICK BEDELL.
J. FRANKLIN STEVENS.	B. A. BEHREND.	BANCROFT GHERARDI.
WILLIAM B. JACKSON.	PETER JUNKERSFELD.	A. S. McALLISTER.
WILLIAM McCLELLAN.	L. T. ROBINSON.	JOHN H. FINNEY.

TREASURER.	(Term expires July 31, 1915.)	SECRETARY.
GEORGE A. HAMILTON.		F. L. HUTCHINSON.

HONORARY SECRETARY.	LIBRARIAN.
RALPH W. POPE.	W. P. CUTTER.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

PAST-PRESIDENTS.—1884-1914.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.

*Deceased.

STANDING COMMITTEES

Revised to March 1, 1915

EXECUTIVE COMMITTEE.

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W. E. and M. Company, East Pittsburgh, Pa
C. A. Adams,
H. H. Barnes, Jr.,
B. A. Behrend,
G. A. Hamilton,
William McClellan,
N. W. Storer.

FINANCE COMMITTEE.

J. Franklin Stevens, Chairman,
1326 Chestnut St., Philadelphia, Pa.
H. H. Barnes, Jr.
B. Gherardi.

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Samuel Sheldon, Chairman,
198½ Schermerhorn St., Brooklyn, N. Y.
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F. L. Hutchinson.
Harold Pender,
W. I. Slichter.

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General Electric Company, Schenectady, N. Y.
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E. E. F. Creighton,
A. F. Ganz,
Dugald C. Jackson,
William B. Jackson,
V. Karapetoff,
S. M. Kintner,
C. S. McDowell,
H. H. Norris,
J. C. Reed,
D. B. Rushmore,
C. E. Scribner,
Clayton H. Sharp,
Charles P. Steinmetz,
H. G. Stott,
Wilfred Sykes,
P. H. Thomas,
J. B. Whitehead.

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239 West 39th St., New York.
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H. W. Flashman,
W. A. Hall,
F. D. Nims,
Charles F. Scott,
and the chairmen of all Institute Sections.

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Harvard University, Cambridge, Mass.
C. A. Adams, Secretary,
Harvard University, Cambridge, Mass.
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W. A. Del Mar,
H. W. Fisher,
H. M. Hobart,
F. B. Jewett,
P. Junkersfeld,
G. L. Knight,
W. L. Merrill,
W. H. Powell,
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E. B. Rosa,
C. E. Skinner,
J. M. Smith,
H. G. Stott,
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H. B. Gear,
H. O. Lacount,
Kempster B. Miller,
H. N. Muller,
H. R. Sargent.
A. M. Schoen,
George F. Sever,
C. E. Skinner,

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C. E. Scribner,
Paul Spencer,
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SPECIAL COMMITTEES

Revised to March 1, 1915

POWER STATIONS COMMITTEE.

H. G. Stott, Chairman,
600 West 59th Street, New York.
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C. A. Hobein,
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C. S. MacCalla,
R. J. S. Pigott,
E. F. Scattergood,
Paul Spencer,
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F. A. Gaby,
L. E. Imlay,
L. R. Lee,
G. H. Lukes,
Ralph D. Mershon,
W. E. Mitchell,
V. D. Moody,
F. D. Nims,
F. W. Peek, Jr.,
Harold Pender,
K. C. Randall,
C. S. Ruffner,
F. D. Sampson,
P. W. Sothman,
C. E. Waddell,
J. E. Woodbridge.

RAILWAY COMMITTEE.

D. C. Jackson, Chairman,
248 Boylston Street, Boston, Mass.
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A. H. Babcock,
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E. P. Burch,
H. M. Hobart,
E. B. Katte,
Paul Lebenbaum,
W. S. Murray,
Clarence Renshaw,
A. S. Richey,
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R. P. Jackson,
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L. C. Nicholson,
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J. A. Osborn,
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H. Mouradian,
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20 Nassau Street, New York.
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14 West 45th Street, New York.
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C. A. Adams,
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Gano Dunn,
H. M. Hobart,
John W. Lieb,
E. B. Rosa,
C. F. Scott,
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Samuel Sheldon,
C. E. Skinner,
Charles P. Steinmetz,
H. G. Stott,
Elihu Thomson,
Philip Torchio.

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100 Broadway, New York.
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13 Park Row, New York.
H. W. Buck,
Gano Dunn,
John F. Kelly,
Schuyler Skaats Wheeler

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Frederick C. Bates, Chairman,
30 Church Street, New York.

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Edward Caldwell,
N. A. Carle,
W. G. Carlton,
W. A. Del Mar,
A. F. Ganz,
Bancroft Gherardi,
E. W. Goldschmidt,
C. A. Greenidge,
A. H. Lawton,
John W. Lieb,
R. R. Livingston,
W. E. McCoy,
William Maver, Jr.,
Angus K. Miller,
F. A. Muschenheim,
Farley Osgood,
H. A. Pratt,
W. S. Rugg,
George F. Sever,
Frank W. Smith,
P. W. Sothman,
S. D. Sprong,
H. G. Stott,
H. M. Van Gelder,
J. M. Wakeman,
Walter F. Wells.
Clifton W. Wilder.

EDISON MEDAL COMMITTEE.

Appointed by President for terms of five years.

Term expires July 31, 1919.

Charles F. Brush, William Stanley,
N. W. Storer.

Term expires July 31, 1918.

H. W. Buck, F. A. Scheffler.
J. Franklin Stevens,

Term expires July 31, 1917.

A. E. Kennelly, Robert T. Lozier.

Term expires July 31, 1916.

Ralph D. Mershon. Frank J. Sprague,
Schuyler Skaats Wheeler, Chairman,
Ampere, N. J.

Term expires July 31, 1915.

J. W. Lieb, E. L. Nichols.
Elihu Thomson,

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.

C. O. Mailloux, L. T. Robinson.
C. E. Scribner,

Term expires July 31, 1915.

H. H. Barnes, Jr., A. S. McAllister.
William McClellan,

Ex-Officio.

P. M. Lincoln, President.
George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

INSTITUTE REPRESENTATIVES

ON BOARD OF AWARD, JOHN FRITZ MEDAL

Gano Dunn, C. O. Mailloux,
Ralph D. Mershon, Paul M. Lincoln.

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C. E. Scribner, H. H. Barnes, Jr.,
Gano Dunn.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

Samuel Sheldon, Harold Pender,
B. Gherardi, W. I. Slichter,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The chairman of the Institute's Code Committee,

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON ADVISORY BOARD, NATIONAL CONSERVATION CONGRESS.

Calvert Townley.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON AMERICAN ELECTRIC RAILWAY ASSOCIATION'S COMMITTEE ON JOINT USE OF POLES.

Farley Osgood, F. B. H. Paine.
Percy H. Thomas.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON BOARD OF MANAGERS, PANAMA-PACIFIC INTERNATIONAL ENGINEERING CONGRESS, 1915.

A. M. Hunt, J. T. Whittlesey.
And the President and Secretary of the Institute.

ON JOINT COMMITTEE ON LEGISLATION RELATIVE TO REGISTERING ENGINEERS.

William McClellan, S. D. Sprong.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10, Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand
T. P. Strickland, N.S.W. Government Railways, Sydney, N. S. W.
L. A. Herdt, McGill Univ., Montreal Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5 Schoeneberg, Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff, Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co. Ltd., Bombay, India.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

LIST OF SECTIONS

Revised to March 1, 1915.

Name and when Organized.	Chairman	Secretary.
Atlanta Jan. 19, '04	A. M. Schoen	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Building, Baltimore, Md.
Boston Feb. 13, '03	G. W. Palmer, Jr.	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago 1893	E. W. Allen	W. J. Norton, 112 W. Adams St., Chicago, Ill.
Cleveland Sept. 27, '07	Howard Dingle	R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio.
Detroit-Ann Arbor Jan. 13, '11	H. H. Norton	Ray K. Holland, Cornwell Building, Ann Arbor, Mich.
Fort Wayne Aug. 14, '08	L. D. Nordstrum	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Indiana.
Indianapolis-Lafayette Jan. 12, '12	J. L. Wayne, 3rd.	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles May 19, '08	C. G. Pyle	Edward Woodbury, Pacific Lt. & Pr. Company, Los Angeles, Cal.
Lynn Aug. 22, '11	W. H. Pratt	F. S. Hall, General Electric Co., Lynn, Mass.
Madison Jan. 8, '09	J. W. Shuster	F. A. Kartak, Univ. of Wisconsin. Madison Wis.
Mexico Dec. 13, '07		
Milwaukee Feb. 11, '10	L. L. Tatum	W. J. Richards, National Brake and Electric Co., Milwaukee, Wis.
Minnesota Apr. 7, '02	Leo H. Cooper	Emil Anderson, 1236 Plymouth Bldg., Minneapolis, Minn.
Panama Oct. 10, '13	Hartley Rowe	Clayton J. Embree, Balboa Heights, C. Z.
Philadelphia Feb. 18, '03	H. F. Sanville	W. F. James, 1115 North American Bldg., Philadelphia, Pa.
Pittsburgh Oct 13, '02	J. W. Welsh	Charles R. Riker, Electric Journal, Pittsburgh, Pa.
Pittsfield Mar. 25, '04	W. W. Lewis	M. E. Tressler, General Electric Company, Pittsfield, Mass.
Portland, Ore. May 18, '09	R. F. Monges	Paul Lebenbaum, 45 Union Depot, Portland, Ore.
Rochester Oct. 9, '14	John C. Parker	O. W. Bodler, Pittsford, N. Y.
St. Louis Jan. 14, '03	S. N. Clarkson	A. McR. Harrelson, 5929 DeGiverville Avenue, St. Louis, Mo.
San Francisco Dec. 23, '04	C. J. Wilson	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady Jan. 26, '03	H. M. Hobart	S. M. Crego, Gen. Elec. Co. Schenectady, N. Y.
Seattle Jan. 19, '04	S. C. Lindsay	E. A. Loew, University of Washington, Seattle, Wash.
Spokane Feb. 14, '13	J. W. Hungate	L. N. Rice, Spokane and Inland Empire R. R. Co , Spokane, Wash.
Toledo June 3, '07	George E. Kirk	Max Neuber, Cohen, Friedlander & Martin, Toledo, O.
Toronto Sept. 30, '03	D. H. McDougall	H. T. Case, Continental Life Bldg., Toronto. Ont.
Urbana Nov. 25, '02	I. W. Fisk	P. S. Biegler, Univ. of Illinois, Urbana, Ill.
Vancouver Aug. 22, '11	E. P. LaBelle	K. C. Auty, B. C. Electric Railway Co., Ltd., Vancouver, B. C.
Washington, D. C. Apr. 9, '03	C. B. Mirick	C. A. Peterson, 1223 Vermont Ave., N. W. Washington, D. C.

Total 31

LIST OF BRANCHES

Name and when Organized.	Chairman	Secretary.
Agricultural and Mech. College of Texas Nov. 12, '09	J. F. Nash	A. Dickie, A. & M. College, College Station, Texas.
Alabama, Univ. of Dec. 11, '14	W. M. Johnston	L. M. Smith, University, Ala.
Arkansas, Univ. of Mar. 25, '04	D. C. Hopper	J. E. Bell, Univ. of Arkansas, Fayetteville, Ark.
Armour Institute Feb. 26, '04	W. L. Burroughs	Chester F. Wright, 3341 Michigan Boulevard, Chicago, Ill.
Bucknell University May 17, '10	R. K. Hoke	George A. Irland, Bucknell University, Lewisburg, Pa.
California Univ. of Feb. 9, '12	L. R. Chilcote	E. S. Meddaugh, 2521 Channing Way, Berkeley, Cal.
Cincinnati, Univ. of Apr. 10, '08	F. Oberschmidt	A. C. Perry, 707 East McMillan Street, Cincinnati, O.
Clemson Agricultural College Nov. 8, '12	W. E. Blake	F. L. Bunker, Clemson College, S. C.
Colorado State Agricultural College Feb. 11, '10	G. M. Strecker	E. O. Marks, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized.	Chairman	Secretary
Colorado, Univ. of...... Dec. 16, '04	Philip S. Borden	Charles S. Miller, University of Colorado, Boulder, Colo.
Georgia School of Technology.............. June 25, '14	R. A. Clay	J. M. Reifsnyder, Jr., Georgia School of Technology, Atlanta, Ga.
Highland Park College.. Oct. 11, '12	Clyde Prussman	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa.
Idaho, University of..... June 25, '14		
Iowa State College...... Apr. 15, '03	Roscoe Schaffer	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......... May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col.,.. Jan. 10, '08	L. V. Fickle	Clarence E. Reid, Kansas State Agric. Col., Manhattan, Kan.
Kansas, Univ. of....... Mar. 18, '08	Ray Walker	Ernest Arnold, Univ. of Kansas, Lawrence, Kansas.
Kentucky State, Univ. of Oct. 14, '10	Harry Y. Barker	G. F. Campbell, 345 South Limestone Street, Lexington, Ky.
Lafayette College....... Apr. 5, '12	R. McManigal	W. J. English, Jr., Lafayette College, Easton, Pa.
Lehigh University...... Oct. 15, '02	N. F. Matheson	F. C. Brockman, 3 North Main St., Nazareth, Pa.
Lewis Institute......... Nov. 8, '07	A. H. Fensholt	Fred A. Rogers, Lewis Institute, Chicago, Ill.
Maine, Univ. of......... Dec. 26, '06	H. H. Beverage	W. E. Bowler, University of Maine, Orono, Maine.
Michigan, Univ. of...... Mar. 25, '04	H. A. Enos	H. W. Stubbs, University of Michigan, Ann Arbor, Mich.
Missouri, Univ of.,...... Jan. 10, '03	E. W. Kellogg	K. Atkinson, University of Missouri, Columbia, Mo.
Montana State Col.,.... May 21, '07	John M. Fiske	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of..... Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A. Lincoln, Nebr.
New Hampshire Col..... Feb. 19, '09		
North Carolina Col. of Agr., and Mech. Arts...... Feb. 11, '10	H. M. Alexander	D. G. McArn, West Raleigh, N. C.
North Carolina, Univ. of Oct. 9, '14	P. H. Daggett	J. W. McIver, University of North Carolina, Chapel Hill, N. C.
Ohio Northern Univ... Feb. 9, '12	R. E. Lowe	W. F. Schott, 426 South Union Street, Ada, Ohio.
Ohio State Univ.,....... Dec. 20, '02	Leslie J. Harter	Robert C. Schott, 38 14th Avenue, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.......... Oct. 13, '11	J. C. Woodson	W. C. Lane, Oklahoma A and M College, Stillwater, Okla.
Oklahoma, Univ. of..... Oct. 11, '12	C. K. Karcher	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon, Agr. Col.,...... Mar. 24, '08	W. R. Grasle	Winfield Eckley, Oregon Agric. Col., Corvallis, Ore.
Penn State College..... Dec. 20, '02	H. S. Smith	Daniel E. Winslow, State College, Pa.
Pittsburgh, Univ. of.,.... Feb. 26, '14	G. W. Flaccus	Ralph C. Zindel, University of Pittsburgh, Pittsburgh, Pa.
Purdue Univ.,.......... Jan. 26, '03	L. W. Spray	R. E. Tafel, Purdue Univ., Lafayette, Ind.
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SECTION II

PROCEEDINGS

of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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FIXATION OF ATMOSPHERIC NITROGEN

BY LELAND L. SUMMERS

Abstract of Paper

The nitrogen contained in the atmosphere is in an inert form and does not readily lend itself to chemical reactions. To overcome this is the province of "nitrogen fixation."

There are very definite commercial limitations involved in accomplishing this as the world's supply of nitrogen has been readily obtained from vast natural deposits of sodium nitrate in Peru and Chile and the production of a substitute must be at a competitive cost.

The electrical processes for fixing nitrogen have a very low efficiency, due to utilizing thermal energy only.

Combinations of electrical and chemical methods promise the most important developments.

Comparative figures are given showing amount of energy necessary per kilogram of nitrogen fixed, and the general economics of the subject are discussed.

Introductory

IN 1898 Sir William Crooks in his address as President of the British Association, very forcibly pointed out that the commercial fixation of atmospheric nitrogen was one of the greatest discoveries awaiting the ingenuity of chemists. He emphasized with very interesting figures its important practical bearing on the future welfare and happiness of the civilized races. This address brought forcibly to the attention of engineers the fact that the existing sources of fixed nitrogen were limited, and greatly stimulated the efforts of investigators. The problem itself had been worked on for over a century as it was known that nature fixed nitrogen of the atmosphere by means of electric discharges, and Cavendish in 1781 had shown that a small amount of nitrogen was converted into nitric acid in the combustion of hydrogen with oxygen to form water, while Bunsen in 1877 obtained favorable yields by means of gaseous explosions. The earlier efforts commercially in the art were however largely confined to the fixation of nitrogen for the purpose of manufacturing cyanides, and the earlier bibliography of the subject therefore deals almost entirely with these efforts.

Commercial Products of Nitrogen. The three fundamental

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commercial products formed by nitrogen are first, its union with oxygen to form nitrates NO_3 and nitrites NO_2. Second, its union with carbon to form cyanogen C_2N_2 and producing cyanides XCN and cyanamides XCN_2. Third, its union with hydrogen to form ammonia, NH_3. From all of the above products there are obtained a large number of derivatives used in the chemical arts.

The most important of all commercial products are the unions of nitrogen with oxygen forming the nitric acid salts of commerce. These are of particular importance on account of the vast natural deposits of nitrate of sodium occurring in Peru and Chile, commonly called Chile saltpeter. Practically, this commodity is the one that sets the price for all other compounds of nitrogen, as it has been mined in Chile since 1830, and during the past 25 years its production has assumed vast proportions, the present annual output amounting to about 2,500,000 tons. This deposit of Chile appeared inexhaustible and therefore there was no occasion for alarm regarding the world's supply of combined nitrogen, but after years spent in exploration work it began to appear that the Chilean deposits would be exhausted before the end of the present century, and since then all other sources of combined nitrogen have received attention.

While there are a few scattered natural deposits other than those in Chile, there is none which has at the present time a chance of competing, most of them being of limited extent and situated in inaccessible regions. In Chile the deposits are easily worked and even after years of careless mining with no effort to effect economics, the present cost of producing nitrate is not excessive, varying from $10 to $20 per ton and selling in Liverpool for about $45 per ton. This leaves a profit of from $5 to $10 a ton on the operation after paying the Government of Chile an export tax of about $12.25 per ton. In the past 30 years this export tax has netted the Chilean Government about $500,000,000. Of the total production of Chile the United States imports about 600,000 to 700,000 tons per annum the balance being practically all shipped to European countries. Chile saltpeter has sold as high as $60 a ton but since 1909 when the agreement among the producers expired the price has approximated $45 per ton f.o.b. Liverpool, making a price of from $35 to $40 per ton f.o.b. Chile.

The union of nitrogen and carbon to form cyanides and with hydrogen to form ammonia are two of the earliest forms in which the combined nitrogen was utilized. Most all animal and vegetable refuse contains ammonia compounds and these were the early sources of ammonia, and animal refuse products such as hides, hoofs and horns were the sources of combined carbon products forming the cyanides. Until the discovery of the McArthur-Forrest process for gold extraction, the markets for cyanides were comparatively limited and there was no great effort made to produce them on a large scale. With the rapid development of this art in the recovery of the low grade gold deposits a sudden impetus was given to the cyanide industry, and large quantities of cyanides are now manufactured from ammonia and metallic sodium. Small amounts of cyanides for industrial purposes are recovered from the gas retort houses but these processes are not generally applied and no particular effort has been made to extend the processes to the recovery of cyanides from by-product coke ovens. The greater portion of the cyanides are manufactured in England and Germany and some 20,000 tons per annum are exported annually by these two countries. As the cyanides of sodium and potassium for gold recovery purposes sell from $300 to $400 per ton, they represent one of the highest prices of nitrogen directly combined with a simple element.

The third great commodity of commerce, ammonia, is utilized extensively in industrial arts but in addition has been used for many years as a fertilizer. The annual production of sulphate of ammonia now amounts to about 1,250,000 tons and the Liverpool price approximates that of sodium nitrate, varying from $45 to $60 per ton. Practically all of this sulphate of ammonia is manufactured from coal distillation either from gas house retorts or by-product coke ovens, up to the past year there having been practically no process in operation for the direct synthesis of ammonia from its compounds.

All the older retort processes for the manufacture of gas, recover ammonia by washing the illuminating gas with water. All by-product coke ovens likewise treat the by-product gas for the recovery of ammonia. American coals run from 0.9 per cent to 1.4 per cent nitrogen or from 18 to 28 lb. (8.1 to 12.7 kg.) of nitrogen per ton of coal. In the distillation of this coal about 20 per cent of the nitrogen is recovered from the gases of distillation so that from 4½ to 7 lb. (2.1 to 3.2 kg.) of ammonia are recovered per ton of coal distilled; this ammonia when united with sulphuric acid forms sulphate of ammonia, giving a yield of from 18 to 28 lb. (8.1 to 12.7 kg.) of sulphate of ammonia per ton of coal distilled. Weak solutions of ammonia water are concentrated from the gas house retorts and the ammonia distilled from this water by breaking down the ammonia contents with lime, the pure ammonia then being united with sulphuric acid. In many of the coke oven plants the sulphate is formed directly by passing the gases into sulphuric acid forming the ammonia sulphate by a direct process.

In general it costs about $15 per ton of ammonia sulphate to manufacture the sulphate from the ammonia, so that if ammonia sulphate is selling for $45 per ton, $15 of this is represented in the cost of sulphuric acid and the manufacturing, making the net ammonia cost with profit $30 per ton of sulphate or as the nitrogen content of the sulphate amounts to 21 per cent, the nitrogen represents an actual value of 7 cents per pound. With the great increase in the number of by-product coke ovens, there has been a greatly increased quantity of ammonia sulphate manufactured, and it would seem that under these conditions the price of ammonia sulphate will tend to diminish rather than to increase. The actual cost to the by-product coke oven plants recovering the ammonia, in addition to the $15 for manufacturing the sulphate of ammonia, will approximate $10 per ton, and if there is any profit to be obtained from the sale of ammonia, they can afford to recover it at this figure.

Another source of ammonia by coal distillation is from producer gas generated on what is known as the Mond system. In this process steam is admitted to the producer in excess, so that the temperature is not permitted to rise to a point where the ammonia liberated by the fuel is decomposed. This excess of steam tends to protect the ammonia and it is recovered from the producer gas by washing. In this process not only the ammonia carried in the volatile products is recovered but also a large percentage which ordinarily remains in the carbonaceous residue of the coke oven and gas house retort. As ordinarily distilled about 50 per cent of the total ammonia of the coal remains in the coke residue and is not recovered. In the producer where this coke is consumed in the presence of steam the total percentage of recovery may be as high as 75 per cent of the theoretical nitrogen contained in the coal, so that from 15 to 20 lb. (6.8 to 9.1 kg.) of nitrogen may be recovered, or in terms of ammonia sulphate, from 60 to 80 lb. (27.2 to 36.2 kg.) of ammonia sulphate may be obtained per ton of coal consumed in the producer.

This type of producer has not been extensively utilized in America as the expense of installation is increased by the necessity of washing a very large volume of low grade gas, the volume of gas per ton of coal consumed in the producer being about 130,000 cu. ft. against about 10,000 cu. ft. per ton of coal as distilled in the coke oven.

A number of these plants have been installed in England and on the continent, but the aggregate of the ammonia sulphate produced is not large as compared to that from coke ovens and gas house retorts.

Available Nitrogen in Commercial Products. The question of the available nitrogen in the various compounds has in a measure determined the price of the product, the utilization in the fertilizer art being practically the basis of fixing the price. For a number of years it has been assumed that the selling price of combined nitrogen would be from 12 cents to 13 cents a pound. Thus Chile saltpeter being about 95 per cent pure nitrate of soda would have a theoretical nitrogen content of about 16.5 per cent or corrected for impurities would have about 15.5 per cent nitrogen.

As the cyanides until recently were not used directly in the fertilizer art and were combined with more expensive products, their price has not been regulated by their content of combined nitrogen. The ammonia used in the fertilizer art is almost entirely used as sulphate of ammonia, on account of the cheapness of the commercial sulphuric acid and the ease of manufacture, and this product would therefore have a theoretical content of 21 per cent of nitrogen.

The above nitrogen products may be considered the fundamental commercial forms in which combined nitrogen enters the market, and while the fertilizer industry fixes the price of combined nitrogen, it is only one of the many industries in which vast quantities of nitrogen are utilized. Thus about 50 per cent of all the Chile saltpeter imported in this country is used in the manufacture of explosives, while an additional 25 per cent is utilized in the arts requiring nitric acid. Of the ammonia sulphate, a very large percentage is used directly as fertilizer, though there is a very considerable demand for use in chemical industries and such commercial applications as anhydrous and aqueous ammonia used in the refrigeration art. Practically all explosives have utilized nitrogen compounds as a principal ingredient. The earlier black gun powder having used Chile saltpeter, charcoal and sulphur and the later so-called smokeless powder utilizes the oxygen carrying property of nitrogen as well as the inherent molecular energy in the production of such high explosives as nitroglycerin, cordite, lydite, mellenite, gun cotton and various other nitro-cellulose compounds, and modified explosives used in industrial work, such as dynamite and various blasting powders.

Fixation Processes. In considering the fixation of atmospheric nitrogen from a commercial standpoint, the limitations will be imposed by the selling price of the natural product from Chile, covering nitrate compounds, and the selling price of ammonia sulphate as obtained from coal distillation, affected as these prices will be by the manufacture of ammonia from atmospheric nitrogen.

In competition with the above sources of nitrogen there has been the constant effort toward the fixation or rather the utilization of some of the vast quantity of atmospheric nitrogen surrounding us.

A list of these fixation processes would contain the names of hundreds of investigators, and from the past twenty years of effort there may develop processes which at present are still experimental; but of the various processes which have reached the state of commercial application there appear to be four distinct lines of development.

First. The production of nitric acid directly from the atmosphere by means of the electric arc. In this process the nitrogen of the atmosphere is directly combined with its accompanying oxygen without utilizing any other chemical substances, the process consisting essentially of a powerful arc furnace through which air is forced, causing at this high temperature the nitrogen to combine with the oxygen forming nitric oxide, NO.

Second. Methods of fixing nitrogen by means of electric furnaces or combustion where the energy of chemical combination is utilized causing the nitrogen to combine with some substance with which there is a pronounced energy of chemical combination. These processes include furnaces utilizing calcium carbide with which nitrogen readily combines to form calcium cyanamide $CaCN_2$, and various processes for making combinations of nitrogen and a basic or alkaline earth metal such as calcium nitride, Ca_3N_2, or magnesium nitride, MG_3N_2, or aluminum nitride, AlN, the chemical action usually forming a nitride or carbo-nitride.

Third. Processes for producing ammonia, NH_3, directly from nitrogen and hydrogen. These include the effort to use the various forms of electric discharge by which the nitrogen molecule may be decomposed and in the presence of hydrogen, form ammonia. As ammonia decomposes at a very low temperature (500 to 1000 deg. cent.) only the silent discharge seems available, and the yields are not commercial. The most promising of all direct ammonia processes seems to be that of Haber. In this process, a catalytic agent is used and under a heavy pressure the nitrogen molecule is decomposed and united to the hydrogen thus forming ammonia. Salts of uranium seem to be preferred as the catalytic agent and have the power of acting on nitrogen at a temperature of about 500 deg. cent.

Fourth. Production of a high temperature by combustion utilizing either catalytic agents or simply by producing a high temperature by means of the explosion or combustion of gases directly combining the nitrogen and oxygen to form nitric oxide, NO. This method early used by Bunsen in the combustion of hydrogen to form water has been applied to coke oven gases by Hausser. A bomb is used and the mixture of gas and air is fixed electrically, the small amount of NO formed is recovered and converted into nitric acid, HNO_3.

The chemical form in which the commercial supplies of combined nitrogen appear on the market is due largely to existing commercial conditions. The nitric acid combined as sodium nitrate occurs in this form simply on account of being naturally produced in this form. The ammonia appears on the market as ammonia sulphate largely on account of the cheapness with which sulphuric acid can be obtained, and the widely distributed plants for its manufacture, making it one of the cheapest and most convenient forms of combining with ammonia. It is probable that in commercial nitrogen fixing plants, if both ammonia and nitric acid are manufactured, one of the most convenient forms for marketing this product will be by using nitric acid in place of sulphuric acid making ammonia nitrate, NO_3NH_4. This product is on the market at present but is only manufactured from sodium nitrate and from ammonia, or in some of the plants where nitric acid is manufactured, ammonia is shipped to the nitric acid plants to be manufactured into ammonia nitrate. The advantage of ammonia nitrate is that it has a nitrogen content of 35% in this respect being a much more concentrated nitrogen product either for the processes of manufacturing other compounds of nitrogen or for use in the fertilizer industry.

Physical Limitations and Those Fixed by Natural Sources. The competition with natural sources will fix the commercial limitations or selling prices for these various nitrogen compounds and in considering the possible developments of the processes it will be interesting to see to what extent they have definite theoretical limitations, as these will greatly affect any comparison of possibilities. Before considering in detail these processes we might endeavor to investigate whether our present conception of the physical and chemical reactions involved impose real limitations, or whether there is an uncertain boundary which further developments may encroach upon, perhaps thus continually improving the efficiency and possibilities commercially. If for instance the nitric oxide processes which utilize only 2 per cent to 4 per cent of the energy supplied to the furnace are limited to this amount by the inefficiency of the apparatus, there is much greater possibilities of development than would be the case if the process has definite physical or thermodynamic limitations, and the present apparatus utilizes a favorable percentage of this possible ultimate limit. To some extent these theoretical limitations are not always sharply defined, and research will extend this horizon, but we may determine some of these limitations quite definitely.

II. THEORETICAL LIMITATIONS

As we are considering this subject from its engineering aspects, it may be excusable to examine some of the theoretical limitations imposed by the laws of physical chemistry, and in reviewing what may be termed elementary formula, it is interesting to note that the investigation of these theoretical limitations has been of fundamental importance to physical chemistry in extending the application of the laws of chemical dynamics.

Molecular Inertness of Nitrogen. The elements carbon, C, and nitrogen, N, possess a marked similarity in the fact that the molecule of each is composed of two or more atoms united together with a bond representing a large amount of energy. Nitrogen, having an atomic weight of 14, has a normal molecular weight of 28, indicating two atoms to the molecule, and in this molecular form it occupies 79.2 per cent of the volume of the earth's atmosphere. To separate this molecule into its constitutent atoms and cause these atoms to combine with other elements is the problem of the fixation of nitrogen. Unless combined in the atomic form, the enormous bond between the atoms causes them to combine upon themselves into the inert form of molecular or atmospheric nitrogen. The ordinary compounds of nitrogen are formed only by the expenditure of a large amount of energy, the union of molecular nitrogen, N_2, and molecular oxygen, O_2, to form nitric oxide, NO, being represented by the formula,

$$N_2 + O_2 = 2NO = -43{,}000 \text{ calories}$$

Or in other words, to form one gram molecule of nitric oxide, NO, requires the expenditure of energy amounting to 21,500 calories.

The general similarity to carbon in this molecular inertness makes an interesting comparison.

Thus

$$C_2 + O_2 = 2\,CO = 58{,}000 \text{ calories.}$$
$$2\,CO + O_2 = 2\,CO_2 = 134{,}000 \text{ calories.}$$

The formation of one gram molecule of CO therefore represents the liberation of 29,000 calories while the formation of one gram molecule of CO_2 from CO represents 67,000 calories or a total of 96,000 calories in the formation of CO_2 from the original elements C and O. When amorphous carbon therefore is caused to assume the gaseous condition and unite with a molecule of oxygen there is liberated 29,000 calories but after assuming this condition in which the molecule is no longer composed of the inert carbon molecule, a second gram molecule of oxygen unites with the CO and liberates 67,000 calories additional. The second molecule of oxygen therefore liberates 38,000 calories more than the first molecule, and as the oxygen molecules were alike this energy represents the bond uniting the carbon atoms and the energy necessary to break down the bond between these atoms and produce a gaseous condition from the amorphous condition.

Returning to the nitrogen molecule, it is apparent that the formation of the gram molecule of NO requires 21,500 calories in comparison to carbon liberating 29,000 calories to form CO; that is, the nitric oxide reaction is endothermic while the carbon monoxide reaction is exothermic. Upon adding a second molecule of oxygen to the nitric oxide to form the peroxide we find,

$$2\,NO + O_2 = 2\,NO_2 = 27{,}000 \text{ calories}$$

or 13,500 calories per gram molecule are liberated after previously expending 21,500 calories to form NO. Since there is liberated only 13,500 calories upon adding a second molecule of oxygen, the net energy required to form the NO_2 would be 8000 calories. The first molecule of oxygen required 21,500 calories whereas the second required only 8000 calories, so that 13,500 calories were required by the nitrogen molecule to prepare it for combination with the oxygen.

Dynamic Equilibrium. These heats of combination developed by the atoms combining upon themselves indicate a very stable or inert molecule, and in liberating this energy to assume this more stable form the forces exerted are of large magnitude. It is readily apparent from this for instance how carbonaceous gases can readily form soot and cinders and other amorphous forms, when the union with oxygen is disturbed, as the tendency of the atoms to unite with oxygen or to form carbon molecules will depend upon an adjustment of the surrounding conditions. This ever-changing condition of equilibrium constitutes the dynamic conception of equilibrium displacing the static equilibrium of the older theories of chemistry. In order to more carefully consider some of the theories that have been advanced it may be of interest to follow further some of the concepts of physical chemistry. The fact that the nitrogen atom has this strong tendency to combine upon itself with a liberation of energy greater than the combination with the oxygen atom, indicates that in any reaction when the combination with oxygen has made possible a changing of the atoms there will be continuously in progress an action and a reaction and the equilibrium will be indicated by the expression

$$N_2 + O_2 \rightleftarrows 2\ NO$$

the sign of equality being displaced by the two arrows indicating that the action proceeds in each direction, that is, it is a reversible reaction, and the equilibrium will be dependent upon conditions, the two most important conditions being temperature and the active masses of the substances present. Considering first the effect of the active masses present, if it be assumed that the collision of molecules causes the re-arrangement of the atoms comprising the molecule, and that of these collisions only a certain number will cause the re-arrangement to proceed in one direction, the re-arrangement will be greater the more frequently the collisions take place, there being some ratio for each individual case, and the collisions possible will obviously be proportional to the concentration present, that is, the collisions will be proportional to the number of molecules present. With two substances present, the collisions will be proportional to the molecules of each present and hence to their product.

The Velocity Coefficient. If C_1 and C_2 represent the special concentration of gram molecules present, the velocity of the reaction will be proportional to C_1C_2 or the velocity V of the reaction will be

$$V = C_1 C_2k$$

where k is a constant or coefficient to be determined for the given temperature. This velocity of reaction will proceed each way in reversible reactions, the concentrations of the molecules in the reverse action being represented by C_1' and C_2' and the velocity of reaction by V', the velocity of the reaction in the reverse direction will be

$$V' = C_1' C_2'k'$$

where k' is the velocity constant to be determined for the reverse reaction.

The Equilibrium Constant. The chemical driving force for any reaction will continually diminish as the reaction approaches equilibrium, or the velocity of the reaction will diminish as equilibrium is approached, and when equilibrium is reached V will equal V' and

$$kC_1 C_2 = k'C_1' C_2'$$

This dynamic equilibrium indicates that as much reactive substance is being formed in a given time as is being decomposed, and a fixed relation therefore results, but the reactions have not ceased, only the velocities have equalized, and the driving chemical forces are incapable of making any further change in the reacting substances unless the velocity in one direction or the other is changed. In this state of equilibrium the ratio between the velocity coefficients or constants is

$$\frac{k_1}{k} = \frac{C_1'C_2'}{C_1C_2} = K = \text{equilibrium constant.}$$

Or, as the concentration or active mass in any reaction increases, the velocity coefficient increases, and for each change in equilibrium due to temperature change, there is a definite concentration ratio represented by this equilibrium constant K.

Partial Pressures. If the concentration of a given molecule is C and the collisions of the molecule are proportional to this concentration, if there are two molecules the collisions between the two similar molecules will be C times as great as one molecule, or C^2. As the total pressure of a mixture of gases is the sum of the pressure of each gas, and by Avagadro's hypothesis the pressure is proportional to the number of molecules in the given space, the concentrations instead of being represented by gram molecules C may be expressed as partial pressures p, and equilibrium will be represented by the ratio of the partial pressures of the gases. Thus two molecules of NO will have the pressure p^2_{NO} while p_N and p_O may represent the pressure of N and O. At equilibrium the constant K will then become

$$K = \frac{p^2_{NO}}{p_N p_O}$$

and for any pressure and volume the familiar equation

$$PV = RT$$

will represent the work done. Where P is the pressure, V the volume, R the gas constant, and T the absolute temperature. The work done in the reaction

$$N_2 + O_2 = 2\,NO$$

will consist in taking one molecule of N from the pressure p and transferring to the pressure P also one molecule of O from the pressure p, to pressure P, and offsetting this work will be the transferring of two molecules of NO from pressure P_{NO} to p_{NO} when the pressure of a gas at constant volume is increased by the infinitely small amount dp, the corresponding work done dA will be

$$dA = dp\,V$$

The Maximum Work. If we substitute for V its value from the equation

$$pV = RT$$

we have

$$V = \frac{RT}{p}$$

and

$$dA = \frac{RT\mathrm{d}p}{p}$$

and for the work done between the limits of pressure p and P we have

$$A = RT\int_{P}^{p} \frac{dp}{p} = RTln\,\frac{p}{P}$$

where *ln* is the natural logarithm. For the work done in forming the NO at a temperature T, we will have

$$\mathrm{N} \quad + \quad \mathrm{O} \quad - \quad 2\,\mathrm{NO}$$

$$A = RTln\,\frac{p_{\mathrm{N}}}{P_{\mathrm{N}}} + RTln\,\frac{p_{\mathrm{O}}}{P_{\mathrm{O}}} - 2\,RTln\,\frac{p_{\mathrm{NO}}}{P_{\mathrm{NO}}}$$

or simplifying and assembling the initial pressures and the final pressures in separate terms, we have for constant temperature

$$A = RTln\,\frac{p_{\mathrm{N}}\,p_{\mathrm{O}}}{p^2_{\mathrm{NO}}} + RTln\,\frac{P^2_{\mathrm{NO}}}{P_{\mathrm{N}}\,P_{\mathrm{O}}}$$

But the first term represents the initial pressures or the work done on the initial condition of the materials, and we are not called upon to furnish this energy, the change of energy being represented only by the second term

$$RTln\,\frac{P^2_{\mathrm{NO}}}{P_{\mathrm{N}}\,P_{\mathrm{O}}}$$

This quantity $\frac{P^2_{\mathrm{NO}}}{P_{\mathrm{N}}\,P_{\mathrm{O}}}$ is, however, the ratio of pressures or concentrations represented by the equilibrium constant K and hence the work done at any given temperature may be represented by the equation

$$A = RTlnK$$

Vant Hoff has applied this type of fundamental equation to a wide range of reactions and by means of the second law of thermodynamics has made it applicable to temperature and concentration changes in which the latent energy plays an important part, for in these reactions the product of the specific heat by the temperature no longer represents the heat transfer.

Vant Hoff's Fundamental Equation. The second law of thermodynamics expresses the relation of A, the maximum work possible at a temperature T, and U, the decrease in energy of the system in relation to the ratio of change of A with the temperature T, the equation being

$$A - U = T\frac{dA}{dT}$$

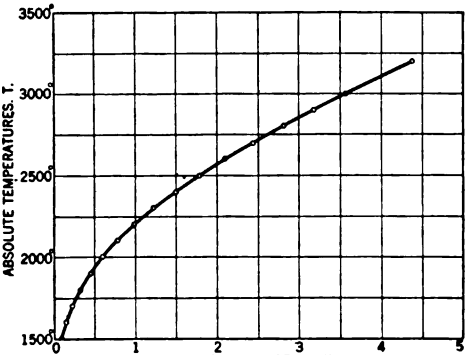

FIG. 1

Substituting in this the value of A and $\frac{dA}{dT}$ obtained from the

equation $$A = RTlnK$$

we have when both A and lnK change with the temperature T

$$\frac{dA}{dT} = RLnK + RT\frac{dlnK}{dT}$$

and hence

$$U = -RT^2\frac{dlnK}{dT}$$

which is Vant Hoff's fundamental equation for chemical reactions in which the heats of reaction U are important factors and both the temperature and concentrations may be variable.

The quantity U, which in thermodynamics represents the decrease in energy of the system, may here represent the energy of chemical combination, which changes very little with changes of temperature and is generally designated as Q, and in the case of nitric oxide it has the value 21,500 calories per gram molecule; so the equation becomes

$$43{,}000 = -RT^2 \frac{d\ln K}{dT}$$

and when using the air as a source of nitrogen in which the nitrogen content is 79.2 per cent and the oxygen 21.8 per cent and letting x represent the percentage of NO formed, as $\frac{1}{2}x$ will be from the nitrogen and $\frac{1}{2}x$ from the oxygen, the equilibrium constant K will be

$$K = \frac{x^2}{\left(79.2 - \frac{x}{2}\right)\left(20.8 - \frac{x}{2}\right)}$$

Nernst's Determinations of Equilibrium. Nernst and his assistants determined x for a number of temperatures, the calculated and observed values being as follows:

T.	X(Obs.)	X(Calc.)	**Observer**
1811	0.37	0.35	Nernst
1877	0.42	0.43	Jellinek
2023 bt. 0.52 and	0.80	0.64	Jellinek
2033	0.64	0.67	Nernst
2195	0.97	0.98	Nernst
2580	2.05	2.02	Nernst-Finckh
2675	2.23	2.35	Nernst-Finckh

Nernst's calculations of x or equilibrium volumes in per cent of NO, using air at temperatures of 1500 deg. T to 3200 deg. T are plotted in Fig. 1.

Rapidity of Dissociation. Nernst and Jellinek also determined the rapidity with which the NO is decomposed or dissociated at the various temperatures and these experiments showed that the tendency of NO to revert to molecular N and O is very slight below a temperature of 1500° C but increases very rapidly with the temperature so that the time of withdrawing the products through the varying zones of heat in the electric arc is sufficient to effect a large amount of dissociation. In order to avoid this dissociation a rapid movement of the air through the arc or the arc through the air is desirable, and this in turn causes increased radiation and convection losses, so the maximum possible temperature of the arc is not obtained and hence there are imposed very distinct limitations to the yield of NO.

Haber's Theory of Ionic and Electronic Collisions. Haber and Koenig investigated the possibility of utilizing lower temperatures in the arc to avoid dissociation by enclosing the arc in a water cooled quartz tube whereby moderate temperatures were preserved. In place of the molecular collisions we have assumed above as due to the thermodynamic condition of the gas, they used a vacuum and endeavored to utilize the kinetic energy from the rapid motion of the ions and electrons liberated by the arc stream under these conditions. Habor considered it possible to increase the thermodynamic concentrations about 50 per cent. His tests indicating that using a temperature of 3000 deg. cent. it was possible to show 10 per cent concentrations of NO which would correspond to a temperature under the thermodynamic equilibrium of 4300 deg. cent. Haber gives a table showing the effect of various mixtures of N and O when working with the increased mean free path of the molecules due to a vacuum of 100 mm. of mercury. In his work Haber prefers to use the square root of the equilibrium constant *K* we have used above, thus enabling the partial pressures of the resulting substances to be read direct, while the partial pressures of the ingredients are expressed as square roots of the pressures.

Haber's table for a pressure of 100 mm. is as follows:

Gas mixture				$K = \frac{(NO)}{(N_2)^{\frac{1}{2}}(O_2)^{\frac{1}{2}}}$	Thermodynamically calculated absolute temperature by	
	O_2 per cent	N_2 per cent	per cent NO		Haber	Nernst
Air	20.9	79.1	9.8	0.284	4365	4334
Half-half	48.9	51.1	14.4	0.337	4686	4650
mixture	44.4	55.6	14.3	0.337	4686	4650
Reversed air	75.0	25.0	12.8	0.357	4805	4767
mixture	81.7	18.3	12.1	0.397	5042	5000

The yields of NO per kilowatt hour obtained by Haber were unsatisfactory and the complications of small water cooled tubes and working under a vacuum of 100 mm. have not justified commercially the higher concentrations of NO he obtained.

Commercial Processes now in Use have Distinct Limitations. We may assume that up to the present the processes in commercial use are limited strictly by the thermodynamic equilibrium of the Vant Hoff equation. As the volume of gases when working with low concentrations of NO are considerable, the radiation and convection losses as well as the transfer of sensible and latent heat from the arc to the gases lower very materially the temperature of the arcs, and the yields therefore indicate an average working temperature of 2200 deg. cent. to 2500 deg. cent., or concentrations of 1.5 per cent to 2 per cent NO when working with air. These theoretical limitations of the direct process of forming NO have therefore led to many efforts to dissociate the nitrogen molecule by other means.

Sources of Chemical Energy. Naturally the sources of chemical energy have offered a most fruitful field but like the synthesis of carbon compounds a considerable elevation of temperature is necessary before the chemical energy becomes effective enough to break the bond of the nitrogen molecule. At these elevated temperatures practically all elements or compounds which release sufficient energy to combine with nitrogen have a greater combining power for oxygen so the processes cannot be conducted with air but involve the separation of the nitrogen from the oxygen of the air as a preliminary step. The compounds of nitrogen thus formed do not therefore include the oxides of nitrogen. The common elements exhibiting the most pronounced tendency to combine with nitrogen are calcium (Ca), magnesium (Mg), aluminum (Al), boron (B) etc. The carbides of a large number of metals also exhibit a pronounced tendency to combine with molecular nitrogen when heated.

The great advantage from a theoretical standpoint in utilizing these processes is that the reaction with nitrogen may be made more complete as equilibrium may be continually disturbed by withdrawing the compound of nitrogen formed or by presenting to the nitrogen to be combined fresh combining surfaces of the substance and the action may be caused to proceed practically quantitatively thus avoiding heating large quantities of materials which are inert to the reaction. A vast field of research is opened by these possibilities as very few of the equilibrium figures have been determined, and it is almost certain that direct combustion methods may eventually be evolved along these lines.

The experimental data are so meager that no theoretical limitations can be placed. The reactions assume unusual importance however on account of a wide application in the arts. This may be best illustrated by considering the formation of calcium carbide, CaC_2, in relation to its three reversible reactions, namely

$$
\begin{array}{lllll}
(1) & CaO + 3C & \rightleftarrows & CaC_2 & + CO \\
(2) & CaC & \rightleftarrows & Ca & + C \\
(3) & CaO + C & \rightleftarrows & Ca & + CO
\end{array}
$$

There are here six substances, some in solid form, some in liquid and some gaseous (molecular and atomic) and it is evident that the temperature will have a marked influence on the equilibrium which will exist, and the reaction will be greatly affected by very minute changes, for the partial pressure of the gases will be suddenly changed by such conditions as the carbon released in a gaseous state immediately combining to form amorphous carbon, or the metallic calcium vapor combining with the oxygen released by the CO to form calcium oxide which immediately precipitates as a solid. The fact that calcium oxide which is most refractory, can be vaporized at a temperature of 1600 deg. cent. to 1800 deg. cent. in the sense that the calcium is vaporized and decomposes CO to again precipitate CaO is one of the actions similar to the fumes in smelting furnaces which accounts for a heavy loss of metal at temperatures not ordinarily capable of producing fusion. When nitrogen is inserted in a reaction of this kind, there are immediately formed complex carbon-nitrogen compounds, but the action of the oxygen present is to dissociate these, allowing the nitrogen to combine into the molecular form and the metal to precipitate from the fume as a minute particle of metallic oxide, the carbon precipitating as amorphous carbon in the form of soot, as all of these reactions liberate a large amount of energy. The temperature of these reactions is from 1500 deg. cent. to 2000 deg. cent. and is therefore well within the range of combustion methods if the combustion could be in contact with the substances as in the blast furnace, but the presence of the oxygen necessary for combustion prevents the formation of nitrogen compounds.

The effect of partial pressures in these reactions is of fundamental importance. The active mass of a solid is constant and hence at the boundary surface where the solid and gases meet there is a high velocity of reaction. Equilibrium will be produced either by the solid forming a coating of the compound which will place it in equilibrium or by the pressure of the gases generated from the reaction producing a condition of equilibrium. Taking the familiar calcium carbonate reaction as an illustration,

$$CaCo_3 \rightleftharpoons CaO + CO_2$$

There being two substances in the solid state and one in the gaseous, the equilibrium constant *K* will be

$$K = \frac{CaO \times CO_2}{CaCO_3}$$

where CaO and $CaCO_3$ are the very slight vapor pressures of the solids, that is the sublimation pressures, which in practice are too small to measure. The pressure of the CO_2 will be practically the total pressure, and as this varies, the velocity constant *K* will vary and hence for any temperature there is but one pressure for equilibrium. LeChatelier measured the temperatures and pressures of the above reaction over a wide range and found a variation in the temperature neccessary to produce the reaction of from 547 deg. cent. at 27 mm. pressure, to 865 deg. at 1333 mm., or in other words, equilibrium could be produced through a range in temperature of 60 per cent., and at one point a change of two degrees necessitated a change in pressure of over 10 per cent. in order to restore equilibrium. Rothmund found the equilibrium pressure of CO in the carbide ot calcium reaction to be 250 mm. at 1620 deg. cent. If the CO pressure was raised above the equilibrium figure at this temperature CO was absorbed and no carbide was formed. By inserting inert gases so the CO was diluted and its partial pressure reduced, the temperature of the formation of carbide was varied over 20 per cent. These results all indicate that for the nitrogen reactions, the actions and reactions must not only be subject to accurate temperature regulation but the partial pressures must be controlled and it is probable that definite zones of reaction must be maintained. The present commercial applications such as the Serpek and cyanamide process prepare the compounds of nitrogen by causing the nitrogen to react largely with the solid masses and thus avoid many of these complications due to the vapor processes, or variable minute pressures of sublimation.

By substituting the resistance furnace for the arc and reducing the metals in the presence of nitrogen thus forming nitrides or forming carbides and treating these in the presence of nitrogen, there have been developed a number of processes which have been commercially applied.

III—DESCRIPTION OF PROCESSES

Three processes which have been commercially applied for directly preparing nitric acid from atmospheric nitrogen are first, Birckland-Eyde; second, the Schonherr; and third, the Pauling. These are diagrammatically shown in Figs. 2, 3, and 5. Fundamentally all operate on the same principle of forcing air into intimate contact with a high-tension arc and withdrawing the product nitric oxide, NO, as directly and rapidly as possible in order to reduce the amount of decomposition of the resulting product. As these processes have been repeatedly described in detail in the technical press, we will confine our attention to general comparisons.

Birckland-Eyde Process. The Birckland-Eyde furnace, illustrated in Fig. 2, has been the most extensively used. Its most distinctive features are the use of the magnets *A* which distort the arc into a series of great wheels of flame, extending radially outward from the electrodes *E* located normal to the paper in Fig. 2. The air enters through the conduit *C* and is distributed to the arc through the holes in the firebrick lining. The products are withdrawn from around the periphery at *D*. The voltage of 10,000 volts is reduced by an inductive reactance coil to about 5500 volts across the electrodes. The alternating current of 50 cycles establishes the arc across the *U*-shaped water cooled electrodes *E*, spaced about 0.3 in. (8 mm.) apart and a flow of current takes place across this ionized path, the electrons formed being repelled by the intense magnet field of the direct current magnets, *A*, and their discharge radially outward causes the arc stream to follow until it is deflected outward in a great semicircle. As its length is thus increased the potential across the electrodes rises and a second arc is established, the effect being to make a series of rapidly expanding arcs which are expanded across the entering air spaces. As the arcs travel radially outward the contact of the ionized arc stream with the incoming air disrupts the nitrogen molecule and causes the formation of NO, and the gaseous products travel rapidly to the periphery of the furnace where they are withdrawn at an average temperature of about 1250 deg. cent. The earlier Eyde furnaces were of 300 kw. capacity and gave a concentration of about 1.5 per cent NO and a yield of about 500 kg. of nitric acid per kw. per year. The more recent furnaces are of 3000 kw. capacity and give concentrations of about two per cent NO and a yield of 580 to 600 kg. of nitric acid per kw. per year, or 65 to 70 grams of nitric acid per kw-hr.

Schonherr Process. The Schonherr furnace (Fig. 3) consists

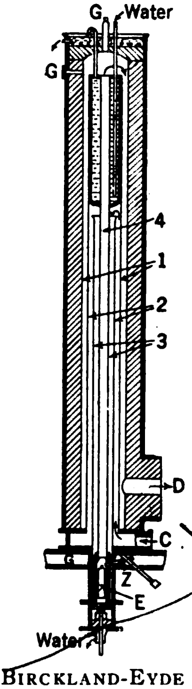

FIG. 2—BIRCKLAND-EYDE FURNACE

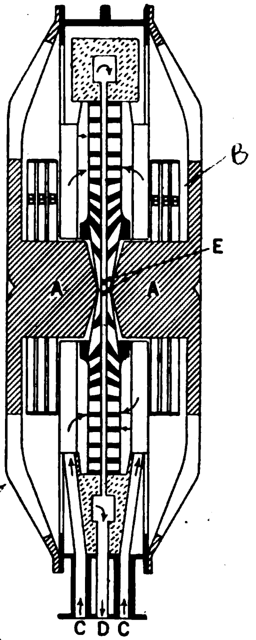

FIG. 3—SCHONHERR FURNACE

A, core; B, windings; C, gas entrance; D, exit.

of a long iron pipe 4 having an electrode *E* inserted in the bottom and the tube itself is the other electrode, the distinctive feature of the process being that an alternating current at 4500 to 5000 volts maintains an arc of from 23 to 25 feet (7 m. to 8 m.) The furnace is started by forming an arc from the lower electrode to the wall of the iron pipe by means of a lever *Z*, a blast of air is then admitted to the pipe, whereupon the ionized gases are caused to ascend and carry with them the arc stream. In this way the arc is caused to travel toward the upper end of the tube where it is maintained. In practise, the air stream is admitted in a tangential direction causing a whirling motion to be imparted to the air surrounding the arc, this creates a vortex motion causing the arc to be surrounded by the cooler air and thus protects the iron pipe which is wholly unlined. The rapid passage of the air maintains an ionized path for the arc stream and the arc burns quietly. The products are withdrawn from the upper end and pass downward through the passes *I* to the outlet *D*. Previous to being withdrawn they are cooled by the water coooler and are further used to preheat the entering air. The temperature of the exit gases is about 850 deg. cent. Provision is made for preheating the air by passing it upward in the space 2 of the casing and then downward to a point opposite the electrode. The largest furnaces are of 800 kw. capacity and maintain an arc about 23 ft. (7m.) long. They give an NO concentration of about 2.25 per cent and a yield of 550 to 575 kg. per kw-year or 65 grams per kw-hr.

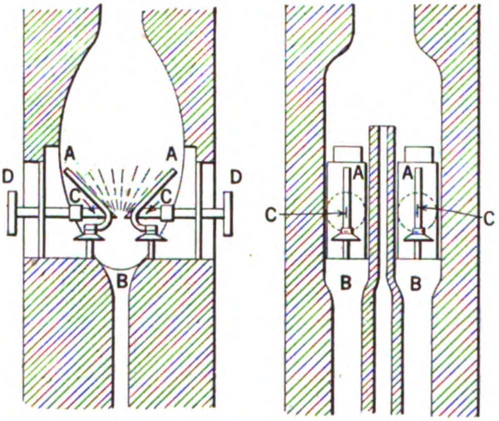

FIG. 4—PAULING NITRIC OXIDE FURNACE

Pauling Process. The Pauling furnace (Fig. 4) establishes an a-c. arc of 4000 volts between two curved horns much after the pattern of the horn type lightning arrester. This arc when established is driven upward by a blast of air admitted at *B* and is disrupted by the diverging horns. A sheet of arc flame is maintained by re-establishing a new arc as the previous one is elongated. The effect is to create an arc flame about 30 in. (75 cm.) high and to have this flame in intimate contact with the rapid moving air used to blast the arc flame. Two furnaces are usually operated together and to assist in a rapid cooling of the products a portion of the previously heated or partially cooled discharged gases are admitted to the top of the furnace. The arc is established by the high voltage breaking down the gap between narrow blades *C* located in the horn gaps, and as these wear away they are continually advanced by the adjustments *D*. The percentage of NO obtained is 1.25 to 1.5 per cent in the 400 kw. furnace while the yields are 525 to 540 kg. per kw-year or 60 grams per kw-hr.

Power Factor and Electrode Wear. In all these processes where the arc is distorted the power factor is about 70 per cent being about 5 per cent lower in the Schonherr type, apparently due to inductive effects of the iron pipe surrounding the arc. In both the Pauling and Schonherr furnaces the electrodes are adjustable and the air blast plays directly on the electrodes necessitating this adjustment and also means of easy renewals. The Pauling blades last less than 24 hours, the Schonherr electrode is a straight rod of iron and is fed upward as it burns away. The Eyde water-cooled copper pipe not being directly in the path of the air blast lasts three to four weeks. In the operation of both the Eyde and Schonherr furnaces a furnace is placed on each separate leg of the three-phase circuit so that six wires are used for each generator. In the installations that have been made the furnaces are connected direct without transformers, and as no parallel operation of generators is attempted a large number of cables are required between the power house and the furnaces.

Efficiency and Losses. It will be noted that notwithstanding the radically different types of these furnaces there is not a wide divergency in the yields, the Schonherr furnace showing the highest concentration of NO while the Eyde probably produces a slightly higher output per kw-hr. All of these concentrations indicate that the maximum temperature of the arc is not utilized but is very considerably reduced by the large amount of air admitted. If the temperature of the arc is raised by admitting less air there is a heavier decomposition of the products and all products are heated to a higher temperature with a corresponding loss, the net result being a lower yield per kw-hr. As the yield per kw-hr. is of fundamental importance, adjustments are governed accordingly. The concentration of NO effects directly the apparatus for recovering the products, such as the absorbing towers, and the lower the concentration of NO the greater the losses from heating the inert gases. The furnace efficiency will largely be determined by this factor. Let us take for example a concentration of 1.75 to 2 per cent NO and examine the distribution of heat. If we take the specific heats of a molecule of the diatomic gases as constant, there will be no difference in the specific heats per molecule of N, O or NO, and taking a standard value for this we may calculate the heat energy expended. Let us assume, following Haber, that for a change of temperature t, the specific heat per molecule will be

$$6.8 + 0.0006\,t$$

The gaseous products heated in the furnace with 1.75 to 2 per cent NO concentrations will have, from Nernst constants, an absolute temperature of about 2500 deg. and the air would have an initial temperature say of 27 deg. cent. or 300 deg. absolute, so the arc would raise the temperature of the 100 molecules through 2200 deg., or,

$$\text{sensible heat} = 100\,(6.8 + 0.0006\,t \times 2200\text{deg.})\;2200\text{ deg.} = 1{,}786{,}400 \text{ calories.}$$

As two molecules of NO require a latent heat of formation of 43,000 calories, the total heat will be 1,829,400 gram-calories; and as one watt hour equals 860 gram-calories the energy represented will be equal to 2.12 kw-hr. for two gram-molecules of NO. Taking the atomic weight of N as 14 and of O as 16, the gram-molecule of NO will weigh 30 grams, so 2.12 kw-hr. will form 60 grams of NO.

If we mix this NO with air and water it will form nitric acid without requiring a further expenditure of energy, thus,

$$2\,NO + 1\tfrac{1}{2}\,O + H_2O = 2HNO_3$$

and the 60 grams of NO will then become 126 grams of HNO_3; the production of nitric acid will then be 126 grams per 2.12 kw-hr. or 59.4 grams of HNO_3 per kw-hr. Of this expenditure of 2.12 kw-hr. the formation of the nitric oxide utilized

$$\frac{43000}{1{,}829{,}400} = 2.35 \text{ per cent,}$$

and the sensible heat imparted to the active gases to raise their temperature to form two molecules of NO required 35,728 calories, so this represented

$$\frac{35{,}728}{1{,}829{,}400} = 1.95 \text{ per cent,}$$

while the heating of inert nitrogen and oxygen or that portion of the air which was not utilized but which was heated to the furnace temperature was represented by

$$\frac{1{,}750{,}672}{1{,}829{,}400} = 95.7 \text{ per cent.}$$

These calculations while open to some criticism on account of the uncertainty of the figures for specific heat and its change with temperature, closely approximate the conditions, and indicate that low concentrations of NO when formed from thermal reactions are extremely wasteful. If concentrations of 10 per cent NO are obtained with temperatures of 4200 deg. to 4300 deg. cent. the yields may be increased to 135 to 140 grams of HNO_3 per kw-hr., but the greatest saving in energy will result in utilizing other than purely thermal energy. While thermal energy may be produced more cheaply directly from fuel, its temperature possibilities are again limited by the inert gases of combustion if air is the source of these.

Hausser has commercially applied a process for utilizing coke oven gases by means of an explosion bomb. The amounts of excess gases may be limited and the intimate mixture of combustible and oxygen due to pre-compression of the charge permits of high combustion temperatures being reached. Fig. 5 shows this bomb having a capacity of 1600 cu. cm. The gases, either illuminating or coke oven gases, enter through the inlet after previously exhausting the air by means of the air pump outlet. Means are provided at *A* for injecting under high pressure a spray of water to cool the products as quickly as possible. The ignition takes place at 2 by means of a high-tension spark and the explosion is propagated outward from this point and the vapor condenses on the enamel lining of the bomb.

With this device Hausser obtained a temp of 2100 T and concentrations of NO of 0.5 per cent. The temperature calculated from the assumed figures for specific heat indicated a concentration of 0.3 per cent for equilibrium by the Nernst calculation and Hausser sought to explain this increase of yield as due to a chemical reaction induced by photo-chemical effects similar to the ionization by ultra-violet or actinic rays of light. The maximum yields were 99 grams of HNO_3 per cu. m. of gas, or equivalent to 6.2 lb. of HNO_3 per 1000 ft. of gas. A commercial plant on this system has been installed in Germany. This low concentration of NO greatly complicates the commercial application as the absorbing devices are more cumbersome and the percentages of loss are higher.

Method of Utilizing NO. All of the above nitric acid processes utilize the reaction

$$2\,NO + O_2 \rightleftarrows 2NO_2$$

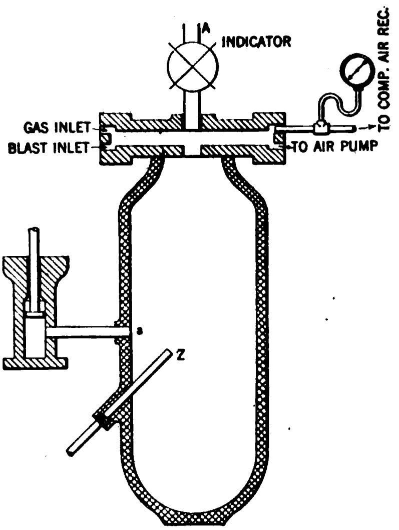

FIG. 5—HAUSSER PROCESS

which is an exothermic one for the formation of the peroxide, and if the temperatures are controlled, side reactions can be prevented and equilibrium can be maintained with only a small percentage of NO remaining. The gases after leaving the furnaces are usually carried through waste heat boilers where 50 to 60 per cent of the heat is utilized for steam production. They are then cooled in aluminum pipe coolers and allowed to enter a gas holder where time is given to form the peroxide. The products then enter counter current absorption towers where the reaction with water forms

$$2NO_2 + H_2O = HNO_3 + HNO_2$$

the nitrous acid HNO_2 is further oxidized and utilized to form HNO_3 in contact with the excess oxygen in the gases and with the absorbing water. The final recovery is usually made by circulating the gases through two towers of weak alkaline solution, such as sodium carbonate and this is converted into sodium nitrate and into sodium nitrite, and recovered by evaporation, the final products are a combined nitrate-nitrite of sodium. A normal circulation over three absorbing towers gives an acid of about 30 per cent concentration but this can be increased to 45 or 50 per cent by recirculating over the first tower. Further concentrations are usually made by evaporation. All of these processes are simplified by increased concentrations of NO in the initial reaction. About two to three per cent of the original NO is discharged in the waste gases from the absorbing towers. It will be noted that one great advantage of these processes is that they require the handling of only air, gas and water up to the time the nitric acid is formed in the absorbing towers, so that the simplest handling devices suffice, and the labor is a minimum, also no chemicals are required until the final washing with the alkaline solution in the absorbing towers, and this may be a cheap solution such as lime water if conditions make it desirable.

Cyanamide Process. The very low yields, representing less than 5 per cent of the energy expended and amounting to 65 kw-hr. per kg. of N fixed, naturally have turned attention to chemical reactions as a means of increasing the yields. One of the most important of these is the process for making cyanamide $CaCN_2$. As a separate paper is to be presented here covering this subject, we will only generalize.

The endothermic reaction and the heating of the materials entering into the calcium carbide reaction have an approximate theoretical value of 3.1 kw-hr. per kg. produced, whereas it requires about 4 kw-hr. to produce a kg. of 85 per cent calcium carbide in the best practise. For 100 per cent carbide it would require 4.7 kw-hr. and the efficiency is therefore,

$$\frac{3.1}{4.7} = 66 \text{ per cent.}$$

The union of carbide and nitrogen is exothermic when a sufficient temperature is reached so the actual expenditure of energy for this reaction is not in excess of 0.1 to 0.2 kw-hr. additional for the fixation of the nitrogen. We require further the preparation of the nitrogen, and the grinding of the carbide to prepare it for the nitrogen treatment. The cyanamide can be used directly in the fertilizer industry, but for use in the chemical industries it must be decomposed to form ammonia, or if nitric acid is required it must be made from the ammonia by some process such as the Ostwald contact process. We may figure however, that the yield for a given amount of electric energy which amounts to about 16.6 kw-hr. per kg of N fixed, is from four to five times the yield of the direct nitric acid processes, while offsetting this is the cost of preparing the nitrogen, the cost of chemicals, the handling of materials at high temperature, and the many factors making up manufacturing costs.

The Serpek Process. The Serpek process is typical and has been quite extensively introduced commercially. The reaction is represented by the equation

$$Al_2O_3 + 3C + N_2 = 2AlN + 3CO$$

The reacting temperature for best results is claimed to be 1800 deg. to 1900 deg. cent., but no effort is made to define the equilibrium conditions and it is very evident that where CO enters so actively into the reaction the temperatures can be materially altered by a change in the partial pressures of the N and CO. One of the most interesting features of this process is that the impure Al_2O_3 in the form of bauxite is fed into the furnace together with coal and the sensible heat is therefore partially derived from the coal. Neglecting the specific heats of the solids, the endothermic reaction requires three kw-hr. per kg. of aluminum nitride, having an approximate content of 26 to 34 per cent N; it would require therefore 9 to 10 kw-hr., per kg. of N under the best conditions if the coal and producer gas were capable of supplying all the heat energy required to produce the required temperature in the gaseous and solid products. In the case of cyanamide it requires about 4 kg. of high grade carbide per kg. of nitrogen or a kg. of N requires 16 kw-hr. under favorable conditions and about 0.2 kw-hr. for heating the carbide against 10 to 12 kw-hr. in the Serpek process. If all energy were supplied from the electric source the Serpek process would require practically the same electrical energy as the cyanamide process.

There is a distinct advantage in being able to use producer gas in place of preparing purified nitrogen and there is a further advantage in conducting the process with one operation. In practise Serpek uses a revolving barrel furnace of the resistance type the resistance consisting of a squirrel-cage construction which continually agitates the material as it passes through. In all nitride reactions this is essential, as the materials become coated with a covering which protects the interior and prevents further absorption of nitrogen. Serpek feeds bauxite and coal from a producer type of furnace into this revolving electric furnace and the sensible heat is thus utilized to heat the material as it travels to the electric furnace the product is discharged from the electric furnace as aluminum nitride with a content of 26 per cent to 34 per cent N.

The aluminum nitride can be treated with steam and the N converted into ammonia or the ammonia may be converted into nitric acid. Serpek claims a process for converting the nitride directly into nitric acid but no details are available. One drawback to using Bauxite is that the resulting aluminum oxide is more difficult to use than the impure bauxite and the process does not work as economically, it is probable that some cheap catalytic agents may be found to substitute for the bauxite but otherwise the Serpek process should necessarily find its greatest application in connection with the reduction of aluminum.

Haber-Catalytic Process. One other process which has attracted marked attention on account of the scientific eminence of its inventor as well as the commercial results obtained is the Haber process for the synthesis of ammonia directly from its components N and H. This means that there must be a supply of these elements available or they must be cheaply produced. The reaction is an exothermic one producing 11,000 calories per gram-molecule so the problem is not so much the energy consumption as the peculiarities of the reaction

$$N_2 + 3H_2 = 2NH_3$$

The ammonia formed is practically decomposed at 750 deg. cent. it has been difficult to get any substance to react with the N at this low temperature, and while the nitrogen was made active toward many substances it was easy to decompose the resulting NH_3 into its constituent molecules and all yields obtained were too low to justify commercial results. Haber's success seems due more to ingenuity in constructing his apparatus and to the discovery of a suitable catalyzer than to any departure from previously known principles. The fact that one molecule of N and three of H form only two molecules of ammonia indicates that the volume occupied by the ammonia will occupy only one-half the space occupied by its constituent gases and hence this contraction of volume will be assisted by pressure. Haber increased the pressure on the reacting gases to 200 atmospheres, and as a catalyzer he used uranium. He found at 500 deg. cent. he could react on the nitrogen and upwards of 8 per cent of ammonia could be formed before equilibrium took place. By using limited amounts of N and an excess of H the equilibrium pressures were adjusted well within the decomposition limits of temperatures and by withdrawing the gases from the catalyzer as they reached equilibrium the process was made continuous. The fact that decomposing ammonia creates a most destructive corrosive agent had to be met and the retorts had to be made strong enough to stand the effects of the high pressure, and also possible explosions, as hydrogen compressed to 200 atmospheres and heated to 500 deg. cent. is a most active agent in the presence of impurities such as oxygen, sulphur, etc. The retorts can be made of very moderate size, and a number of them used and by heating internally with electric resistance the shells are not subject to the effects of temperature, so the process seems to have met with very pronounced technical success. The consumption of energy for heating the gases is very slight as the exothermic reaction will compensate largely for the heat required to release this.

The preparation of the N and H and the compressions to 200 atmospheres will represent the greatest costs of production. It will be noted that all products are handled in the gaseous condition, being most favorable for low labor costs. The ammonia is extracted from the mixture of N and H by slightly cooling the gases until the point of liquefaction of ammonia is reached and the ammonia condenses out. The remaining gases are passed back to the retort without sacrificing the original pressure of compression. The work done on the gases is thus reduced to a minimum and equilibrium can be continually disturbed by withdrawing the products without heavy losses. This process involves the expenditure of approximately 1.5 kw-hr. per kg. of N and therefore represents the lowest consumption of energy of any of the fixation processes.

From an engineering point of view the various processes must be considered from other than the technical standpoint, the question of particular application being the guiding consideration in most cases.

IV—THE ECONOMICS OF NITROGEN FIXATION

Fertilizers. In considering nitrogen fixation and its relation to fertilizers we must remember it is only one of the three important ingredients of fertilizers, the other two being phosphorous and potassium. It is possible to obtain nitrogen from the atmosphere and transfer it to the soil by means of nitrifying bacteria which may be cultivated by such plant life as the legumes, to which family belong the clover and alfalfa. These plants have a nodule on the stem which is the seat of the bacteria activity and if the plants containing this nitrogen are returned to the soil the soil may be enriched in nitrogen, but the crop must be sacrificed or partially so. When it is not desirable to plant these nitrifying crops recourse must be had to nitrogen in the form of fertilizer. Unfortunately all crops deprive the soil of fertility, and in the case of phosphorous and potassium converted into the crops, these must actually be replaced, or barren soil will eventually result. Each soil must be treated for the particular crop it is to bear and usually there are fixed mixtures which become standard for various crops. These mixtures contain the nitrogen the phosphorous and the potassium in varying amounts. The output of nitrogen from a chemical works would ordinarily be shipped to these fertilizer manufacturers unless the chemical works desired to manufacture the mixed fertilizers.

Of all the processes we have considered the cyanamide is the only one which manufactures a product which is in a form to go into the fertilizer market direct. The nitric acid processes must unite the acid with some alkaline base such as sodium, lime or ammonia and the ammonia processes must unite the product with an acid such as sulphuric or nitric. The nitride processes can hardly afford to ship the nitride, as it is combined with an ore or base such as aluminum oxide which may be more desirable in the aluminum industry, as the fertilizer industry will pay only on a nitrogen basis.

Prices of Nitrogen. In general the price of combined nitrogen as we have seen, is fixed by the price of Chile nitrate. Thus if this sells for two cents per lb. and contains 15 per cent N the price per lb. of N is 13.2 cents and this in turn would make the price of ammonia sulphate having 21 per cent of nitrogen 2.7 cents per lb. These have been current prices. In considering the production of nitrogen products, it would seem that while these prices control nitrogen for the fertilizer industry, it would be desirable to produce if possible products which are manufactured from these crude products, and thus avoid competition with the natural products direct. Nitric acid of commerce is manufactured from soda nitrate by treatment with sulphuric acid, about 72 per cent of the sodium nitrate being nitric acid. As the by-products of this operation only partially pay, the costs, the manufacturing costs leave the nitric acid with a value of 50 per cent over the value as nitrate. Hence a chemical works could afford to produce nitric acid when they could not afford to add a manufacturing cost to produce a fertilizer from the nitric acid and then sell it in competition with the crude Chile nitrate.

A large portion of the phosphate rock of this country is treated with sulphuric acid to form the so-called super phosphates. If nitric acid is used in place of sulphuric acid the super phosphate can be produced at the same time as a fertilizer of lime nitrate, or if preferred a high concentration of phosphoric acid can be produced from lower grade phosphate rock. Industries of this kind promise more favorable results commercially than does the direct production of fertilizer. If low grade products are manufactured at close prices a very large volume of business is a necessity and works of this character and magnitude are more apt to be a result of successful development rather than an initial venture in a field beset with uncertainties as to the profits and the chances of a development of other processes reducing these if they are problematical.

Costs of Making Products. Let us consider more in detail some of the costs. We may assume approximately that the labor and repairs in furnace room and absorbing tower will cost $10 per ton of nitric acid and if nitric acid is selling for $60 per ton, we have a margin for power cost, interest, general expense, etc. of $50, and if we produce 500 kg. of acid per kilowatt year it will require two kw-yr. per metric ton or $25 per kilowatt-year, and we must absorb all interest charges and general expense in this. If the yield can be made 550 kg. per kilowatt year and we can sell for $60 per short ton, we will require 1.8 kw-yr. or $28 per kw-yr. We must assume that the product does not have to be packed for shipment and that there are no selling costs involved, and we must figure on an output so that our units may be large enough to bring the investment in plant down to $80 per ton of acid so the annual charge may be $8 or net $20 per kilowatt-year, and if $5 are allowed for general expense the best we can do will be about \$15.00 per kilowatt-year.

We see it would be hopeless to attempt to put this acid into a product to compete with the fertilizer prices, for they are some 50 per cent lower in selling price, and it will involve a cost for some raw material to mix with the acid, the cost of manufacture and a packing and shipping charge. We must then abandon any idea of making fertilizer from nitric acid prepared by the direct oxidation of atmospheric nitrogen in the electric arc until such time as we can improve the very low efficiency due to the thermodynamic limitations of the reaction. We can only hope to utilize this process in the manufacture of nitric acid coupled with some other product which will procure for it a higher price. There is for example a limited demand for the nitrite of sodium $NaNO_2$ used in the dye industry and this is manufactured by reducing nitric acid with molten lead thereby adding another manufacturing operation to the acid cost. This nitrite may be cheaply made by taking a mixture of NO and NO_2 such as we would have in parts of the system and passing it into water or sodium hydroxide, thus

$$NO_2 + NO + H_2O = 2\,HNO_2$$

or,

$$4NO + 2\,NaOH = N_2O + 2\,NaNO_2 + H_2O$$

and this process would produce a product selling for four to five cents per lb. We must remember, however, that the price of nitric acid is not a fixture and that a cheap combined nitrogen fertilizer will cut the price of sodium nitrate and hence the price of nitric acid. We are confronted then with the fact that all processes will be affected by the success of any one process that is a large enough success to affect the market conditions of combined nitrogen and upset the ruling prices in the fertilizer industry. It is useless to look only to cheap power as a solution of this problem as the real solution is in the improvement of processes.

Let us roughly compare the power requirements of the processes as we have outlined them above and we find

Direct oxidizing of atmospheric nitrogen 5 per cent. efficiency, yield at 550 kg. per kw-year, requires per kg. of N.	65 kw-hr.
Cyanamide process 66 per cent. efficiency in carbide 1 per cent. loss in heating to combine with N., requires per kg. of N,.	16.6 "
Also preparation of N.	

Aluminum nitride using coal to heat products to temperature of reaction requires per kg. of N.......	12	kw-hr.
Catalytic method of combining N and H to form ammonia, requires per kg of N..............	1.5	"
Also preparation N and H, refrigeration, and compression to 200 atmospheres.		

The general tendency abroad in figuring the cost of water power is to give only the operating costs and from this one sees costs of producing power figured at from 50 cents to $1.00 per kilowatt year and in using these figures erroneous ideas have been widely circulated. In this country it has been standard practice to consider the investment in the power plant, that is, the cost of the development and the property, as fixing very largely the cost of producing the power. It is quite common to have labor and supplies cost not more than one dollar per kilowatt-year, but this would not be considered as representing the cost of the power. Where a chemical industry owns the hydroelectric power plant as well as the chemical works, the foreign practice is inclined to consider the investment as a whole and apportion the costs of operation to the various departments, while interest on the capital is charged to the profits. The costs of producing power are therefore uniformly much lower than we are accustomed to figure on. There are many plants in operation in the chemical industries abroad whose real costs of producing power are no lower than many of the more favored locations in this country.

Off-Peak Loads. One of the chief interests in the chemical utilization of electrical energy is, centered in the possibilities of off-peak or off-season loads, as American plants generally have a certain proportion of power which can be disposed of to better advantage than selling the entire output as low priced power to chemical industries. This off-peak power is difficult to utilize in furnace work, where the cooling of the furnace and its charge is an important factor both from the standpoint of cost and of output, and again, adjustments may be so disturbed from an interrupted output as to be absolutely impracticable. One of the possible solutions for off peak utilization appears to be in the adoption of some system where fuel is also utilized and the radiation losses are not excessive under conditions of banked fire when the electric portion of the heat energy is not in use. Some of these combination processes may promise a solution of the off-peak load situation more attractive than the straight electric furnace, which is difficult to cool down entirely without unduly affecting the conditions. In all plants the volume of output is the determining factor in absorbing the general overhead charges, and any intermittance must diminish output with its accompanying disadvantages.

If the furnace could be operated on the off-season load and its product stored, and the chemical works utilizing this product could operate on a normal schedule, this would form one solution; or another would be if by chance the off-season power were available at the time the greatest demands were to be met, such as preparing a fertilizer product at the season of fall rains for the early spring delivery. All of these plans however suggest the necessity of operating at least a portion of the plant continuously in order to meet fixed charges and preserve an operating organization. If the chemical works requires a moderate amount of power for its processes in year around operation and only its surplus for manufacturing its crude material at the off season peak it promises the greatest possibilities.

The future of nitrogen fixation is alluring and promises, many developments along lines other than those we have considered, but already the market has felt the effects of these various processes and instead of nitrogen being figured at thirteen cents per pound, it is confidently predicted it will very shortly find its level at a selling price of about eight cents, making a cost of production of five to six cents per pound and thus reducing sodium nitrate to about 1.33 cents per pound, or approximately $30 per long ton, and the lower grade mines will feel this and be forced to curtail.

It therefore seems very certain that before 25 years shall have elapsed since Sir Wm. Crook's made his memorable address, the Chile nitrate beds will have vastly curtailed their production, not from exhaustion but from the inroads made by the onward advance of chemical and electrochemical engineering.

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SOME TROUBLES ENCOUNTERED IN THE OPERATION OF CARBON BRUSHES IN DIRECT-CURRENT GENERATORS AND MOTORS

BY E. H. MARTINDALE

ABSTRACT OF PAPER

This paper deals very briefly with troubles which affect the operation of carbon brushes on motors and generators. It should be of great assistance to the operator in locating various machine troubles and in securing the best service from his brushes. The paper is divided into five sections, based on the location of the cause of trouble: (1) field, (2) armature, (3) commutator, including brush rigging, (4) external electrical, and (5) external mechanical.

IT IS the purpose of this paper to so discuss the causes an effects of troubles encountered in the operation of motors and generators that the operator will be better able to use his brushes to the best advantage.

The characteristics of carbon brushes which most commonly affect the operation are resistance, hardness, abrasiveness, coefficient of friction, contact voltage drop and heat conductivity. None of these terms needs explanation but the writer wishes to emphasize the importance of not confusing hardness with abrasiveness. By abrasiveness we mean the scouring or cutting action of the brush. Hardness of carbon brushes can best be determined by the use of a scleroscope, an instrument used to determine the hardness of steel and other metals. Relative hardness may be judged by cutting the brush with a pocket knife or by marking with it on paper, or if more accuracy is desired by the layman, a set of pencils from 2 B to 8 H will be a great aid, as a pencil softer than the brush will mark it and one harder will scratch it. The hardest brush with which the writer is familiar has no abrasive action, while one of the softest brushes has a decided abrasive action.

In this paper the brush troubles will be divided into five classes depending on the location of the cause of trouble, (1)

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field, (2) armature, (3) commutator, including brush rigging, (4) external electrical, and (5) external mechanical.

FIELD TROUBLES

As the field coils are connected in series or series parallel, a partial short circuit may occur in one coil without materially affecting the heating of the coil. This will usually be attended with severe sparking at one or two studs, although in a wave-wound machine the commutation may be very little affected. This trouble can best be located by the voltage drop across each coil, with a constant current through the coils. Similar trouble may be caused by an error in rewinding a field coil. On some machines the shunt fields are connected with two or three fields in series and two or more of these groups in parallel. A partial short circuit in one coil will then affect the entire group, electrically unbalance the machine, and cause heavy short-circuit currents.

In a cumulative compound machine one series field may be reversed accidentally with the result that as the load increases sparking will occur usually at the two adjacent studs; or the entire series fields by mistake may be connected to oppose the shunt field which will result in blackening of the commutator, and severe sparking under heavy loads. The best way to detect this trouble is to excite separately the shunt field and the series field, being sure that the current flows in the same direction as when the machine is in operation. The polarity of each pole should be tested with a compass and should reverse as the compass is passed from one pole to the next. Further the polarity of each pole should be the same when either field is excited. In a generator the voltage will decrease and in a motor the speed will increase as the load increases.

Unequal air gaps are responsible for a great deal of commutation trouble. If one pole face is nearer the armature the flux across the gap is greater and a higher voltage will be developed in the coils under that pole. This may result in very heavy short-circuit currents between the studs adjacent to that pole and other studs of the same polarity. Fig. 1 shows such a condition due to worn bearings which allow the armature to run nearer the lower pole pieces. In machines with cast frames, blow holes may be present, and may be large enough to greatly increase the reluctance of the magnetic circuit and cause a lower voltage to be developed in one section of the armature with resultant short-circuit currents.

ARMATURE

An open circuit in an armature coil causes the most vicious form of sparking, which is always accompanied by severe pitting of the mica between the commutator bars connected to this coil and the adjacent coil. The usual method is to connect an incandescent lamp in a circuit, and with two pointed terminals make a bar to bar test on the commutator; the open circuit is shown when the lamp does not light. Similar sparking in a less degree may be caused by a high-resistance connection between the end of a coil and the commutator riser. This can be detected by passing a current through the armature and taking voltage drop between adjacent bars, as the voltage will be higher than normal when the poor connection is in the circuit measured. This method may also be used to detect an open circuit, but a voltmeter reading as high as the voltage impressed on the armature must be used, as full voltage will be obtained across the open circuit.

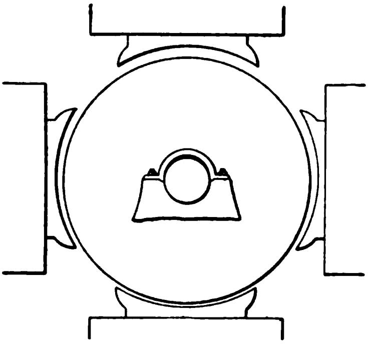

FIG. 1

A short circuit between two sections of a coil, two coils in the same slot, end connections of two coils, or between the commutator bars, will be evidenced by excessive heating of the coils affected, and unless repaired will sooner or later result in a burned out coil. The same method may be used as in the preceding case and the voltage between adjacent bars when the coil is in the circuit will be below normal.

The demagnetizing and cross-magnetizing actions of an armature have serious effects on the commutation of many machines. To get good commutation in a non-interpole machine, the brushes usually must be set ahead of the mechanical neutral on a generator and back of the mechanical neutral on a motor. Fig. 2 shows a sketch of a generator in which the brushes have been shitted ahead of the mechanical neutral 10 deg. The section between *a* and *b* and *a′* and *b′* acts as an electromagnet with poles at N'' and S'' opposing the field magnetization. This is the demagnetizing action. The section *b*, *a′* and *a*, *b′* acts as an electromagnet with poles at N' and S'. This is the cross-magnetizing action of the armature and it tends to increase the magnetism of the right hand side of *N* pole of Fig. 2 and the left hand side of *S* pole, and tends to decrease the magnetism of the left hand side of *N* pole and the right hand side of *S* pole.

If the brushes are shifted far to obtain good commutation, and if, at the same time, the magnetization of the pole piece is not well above the knee of the saturation curve, the demagnetizing effect of the armature may seriously reduce the voltage of a generator or increase the speed of a motor. On the other hand, the cross magnetizing effect may be sufficient, if the brushes are not shifted to the electrical neutral, to place the coils undergoing commutation in a heavy field, with resultant heavy short-circuit currents, severe sparking at the brushes and all the attendant evils. The remedy is to widen the neutral field by filing away the edges of the pole pieces. The object of interpole windings is to counterbalance armature cross magnetizing action and thus maintain the electrical neutral at the mechanical neutral under all conditions of load. In this case there is no demagnetizing action of the armature current, as this occurs only when the brushes are shifted from the mechanical neutral.

COMMUTATOR

Commutator brush troubles are numerous, and often difficult to identify. One of the most troublesome problems with non-interpole generators or motors which do not operate at constant load is the difficulty of finding a point at which the brushes will operate at all loads without injurious sparking. This is due to the cross-magnetizing action described in the preceding paragraph. The brushes are usually set according to the judgment of the operator.

Spring tension or the pressure with which the brushes bear on the commutator seldom receives proper attention except in large central stations or mills and even there it is often neglected. The most economical pressure is the lowest consistent with a low contact loss, a clean commutator and freedom from sparking, glowing or pitting of the brushes. It is seldom advisable to use a pressure less than 1½ pounds per square inch of cross-section. The writer recommends on stationary machines a pressure of from two to four pounds per square inch depending on local conditions and the grade of brush. He recommends from four to eight pounds per square inch for crane motors, haulage motors, railway motors and similar machines. On stationary motors he has found pressure as low as one quarter pound per square inch and as high as fifteen pounds per square inch.

Brush spacing is very important but usually neglected. In Fig. 3 the studs are equally spaced and the dotted lines show the correct brush position, but due to the brush holders on arm *A* being rotated too far in one direction and on arm *C* too far in the opposite direction the voltage generated in section *A B C* is different than in *A F E* or *C D E* and this will result in short-circuit currents between *A*, *E* and *C*, high enough to neutralize the unequal voltage.

The magnitude of this short-circuit current may be illustrated

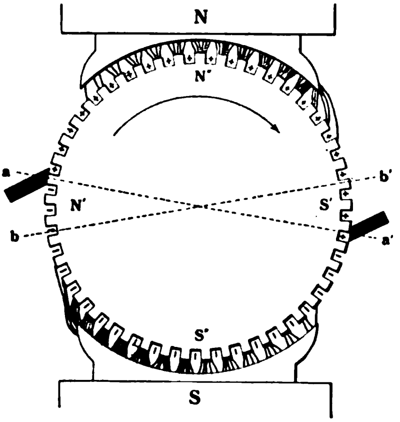

FIG. 2

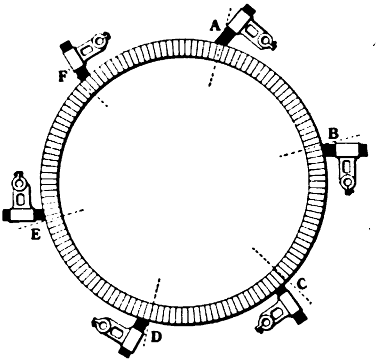

FIG. 3

by a test conducted a few years ago by the writer on the 400-ampere 250-volt 600-rev. per min. six-pole shunt generator shown in Fig. 4. On one positive stud which we will call *A* the brush holders were rotated to place the brush $\frac{3}{4}$ in. ahead of correct position. The other positive studs *B* and *C* were left unchanged. The busbar had been calibrated with a millivoltmeter to determine the current flowing. With the brushes incorrectly spaced but operating at the best point, the short-circuit current was not excessive. When the brushes were shifted two bars away from the neutral and with no external load on the machine the short-circuit current rose to 800 amperes or twice the normal full load current of the generator. As the voltage back of this current was low the actual power loss was small but the heating of the windings and the effect on commutator and brushes was serious. The current density in the brushes on stud *A* was over 200 amperes per square inch and on studs *B* and *C* over 100 amperes per square inch. This is an extreme case, but a smaller difference in spacing may often be serious. Spacing may be checked by counting the number of bars between each pair of studs but a better way is to cut a strip of paper the length of the commutator circumference, mark off equal divisions corresponding to the number of studs, place the paper on the commutator and make the brushes toe the mark.

From the time a commutator bar touches one edge of a brush until it leaves the opposite edge, the current in the coil undergoing commutation should fall from full load to zero and rise in the opposite direction to full load. If the current in the coil is more or less than that value the final adjustment comes as a sudden rush of current as the bar leaves the brush. In many machines the time of commutation is less than 0.001 second. The brushes should therefore be shifted to a point where the coils undergoing commutation are in a field strong enough to make this change. As the cross magnetizing action of the armature tends to shift the field in the wrong direction to accomplish this, the brushes must be shifted farther than if the cross-magnetism were not present. If brushes are too thin, sufficient time is not allowed for commutation, and if they are too thick the coil may over-commutate. In any case, if there is a difference between the correct and actual values of the current in the coil there will be an inductive kick when the bar leaves the brush. If the inductance of the coil is high or the difference in current great, more or less severe sparking may result. Many cases of sparking have been cured by reducing the thickness of the brush.

A similar condition sometimes arises when the brush studs or brush holders are not parallel to the commutator bars. The short-circuit current in this case passing from one brush through the stud to another brush and thence through the coil. Such trouble is often found on some old machines still in service, on which the brush holders and brushes change position as the brushes wear away.

If there is not sufficient clearance between a brush and its holder or if foreign matter becomes lodged in the holder the brush will not move freely and may make poor contact and result in blackening of commutator, sparking, heating and other evils.

PLATE XV.
A. I. E. E.
VOL. XXXIV, NO. 3

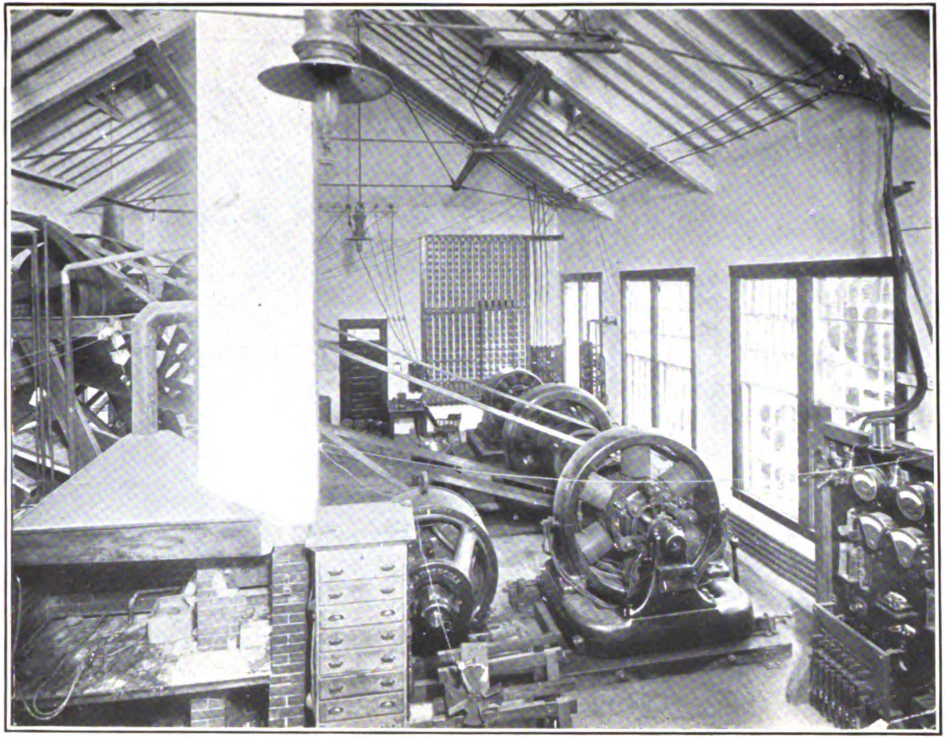

FIG. 4

[MARTINDALE]

On the other hand if there is too much clearance and the brushes are not equipped with shunts the current may pass from the brush to the brush holder through a small arc and cause undue wear of the holders. On machines which have been in service a long time much trouble frequently arises from worn holders. This is particularly true if the machine runs in both directions, as the brush face changes when the machine is reversed and thereby reduces the time of commutation and increases the current density in the brush faces. Brushes in worn holders are also more inclined to chatter and chip.

There are many types of brush shunts or pigtails on the market; some have a relatively high resistance when manufactured, while others become loose due to heating or vibration and cause a large proportion of the current to pass from the brush directly to the holder. A poor connection between the terminal and the stud may have the same effect.

Sometimes the hammer which bears on the brush becomes bent and does not bear evenly or radially on the brush. This may cause such a side push or twist that the brush will not move freely in the holder, and may cause sparking, burning and the attendant evils.

Brushes are sometimes ordered longer than standard with a view to securing a longer life, but the spring will usually give a side push and cause trouble, which will shorten the life of the brushes and perhaps damage the commutator.

Noise of carbon brushes is due to a mechanical vibration called chattering. If due to the friction of the brush on the commutator the noise may have various pitches. The remedy is a change in spring tension, angle of operation or grade of brush although relief may be obtained by lubrication of the commutator at intervals. If the noise is due to high mica or wide slots in a slotted commutator the pitch of the sound will correspond to the number of bars passing under the brush per second. If the trouble is high mica the remedy is the removal of the cause of the high mica or the use of a more abrasive brush or undercutting the mica. If the noise is caused by slots it may be necessary to change the spring tension, angle of operation, or grade of brush as lubrication is not advisable on a slotted commutator.

The causes of short-circuit currents have been mentioned under other heads in this paper and are, briefly: operation of brushes at wrong commutation point, incorrect brush spacing, brushes spanning too many bars, brushes not parallel with commutator bars, field trouble, including unequal air gaps, and to these might be added brushes with too low contact drop. Short-circuit currents represent a low power loss but are serious in their effects on operation. They may produce excessive heating, sparking, high mica, blackening of commutator, burning away of commutator, flat spots, pitting or honeycombing of brush faces, picking up copper by brushes and short life of brushes. The remedy is to find and remove the cause, not always an easy thing to do.

As the expression " short-circuit currents " is not entirely distinctive the writer would like to see some other phrase adopted as standard, such as " trouble currents." This name would be well suited as they never do any good and always do some harm if no more than wasting energy by unnecessary heating.

Pitting or honeycombing of brush faces is nearly always caused by short-circuit currents or a very low brush pressure but occasionally it is due to insufficient carrying capacity of the brushes. It can generally be determined from the appearance of the brush face whether the pitting is caused by low pressure or short-circuit currents; in 95 per cent of the cases it is the latter. Many cases of pitting may be corrected by reducing the thickness of the brushes but it is better practise to look for some other cause first, as already described.

The writer has never been satisfied with any explanation he has seen for " picking up copper ", which term is applied when particles of copper from the commutator become imbedded in the brush faces. It is generally attributed to an electrolytic action, and it is a fact that when the trouble appears it is nearly always on the positive brush of a generator, the negative brush of a motor or a brush which shows heavy short-circuit current. This bears out the theory that the copper is carried by the current and deposited on the brush. On the other hand, the writer has seen a brush pick up copper when running under test on a copper slip ring without any current flowing. This purely mechanical action was attributed to abrasive material in the brush which tore off the copper particles. As the abrasive particle no doubt reaches a high temperature a small copper particle may become welded to it and other particles collect on this until the abrasive spot is itself worn away. Picking up copper lowers the contact resistance between brush and commutator and generally causes heavy short-circuit currents.

A loose commutator bar may be flush with other bars when the machine is stationary but may be thrown out slightly when running, due to centrifugal force. This will lift the brush, and will burn one or more bars just ahead of the high bar, depending on the number which the brush spans, and further, will burn some of the bars back of the high bar depending largely on the speed of the machine and the brush pressure. Its presence can often be detected by the knocking sound of the bar hitting a brush once every revolution.

Commutator bolts should be tightened a few months after the machine has been placed in service. The writer knows of one case where high bars appeared to be causing trouble, and the commutator bolts were tightened, but to no avail. The machine was then dismantled and it was found that the V-ring reached its seat before clamping the commutator bars tightly.

In repairing commutators and sometimes in manufacturing them, commutator bars of different hardness are used and one bar may wear faster than another, causing a flat spot or a high bar.

Necessarily, many of the troubles overlap and some causes for high mica have been given previously in this paper. They are, mainly, some form of sparking which burns away the commutator bars leaving the mica to project. If the cause cannot be located and removed it is necessary to undercut the mica or use a more abrasive brush. The former is preferable, as the life of the commutator and brushes will be longer. When the mica once becomes high it holds the brush from the bars, causes more burning, and the commutator rapidly becomes worse.

Blackening of a commutator may be caused by sparking, the use of too much lubricant or by the character of the brush. Blackening will sometimes occur on every other bar or every third bar, corresponding to the number of coils per slot and may often be shifted to another set of bars by shifting the location of the brushes. This seems to be due to a magnetic kick in the coil undergoing commutation when the armature tooth next to the coil suddenly leaves the field. The remedy is to have the neutral field wide enough to permit the tooth to leave the strong field before the commutator bar comes under the brush.

Flat spots consist of a few bars between which the mica is high. They may be started by the commutator not running true, soft bars, difference in hardness of mica, surges of current or any sparking which occurs once every revolution. When a flat spot starts it may soon develop other flat spots, equidistant about the commutator, one for every pair of poles. This is probably explained by the fact that when the flat spot reaches a brush the current through that brush is greatly reduced. This throws the extra load on the other studs of the same polarity and may produce a spark at each of the studs. Unless given prompt attention the spots may gradually spread until high mica is present over the entire commutator. The cause for the flat spots should be located and removed if possible. An interesting case was recently called to the writers attention by Mr. A. M. Lloyd. A 200-h.p. 250-volt six-pole motor with 30 brushes, had for some time persisted in developing flat spots. The commutator was carefully cleaned and on one section brushes were installed on only two studs. In a few days flat spots had developed on all of the commutator, except that section; two more brushes were added and still no flat spots on the section; the other two were added and the flat spots developed in a short time. One brush was removed, the commutator cleaned and no flat spots developed in this section. This narrowed the trouble down to one stud. A careful investigation showed that the air gap under one of the two adjacent poles was about 8 per cent greater and under the other about 5 per cent greater than under the other four poles. This was evidently due to worn bearings caused by a combination of belt pull and the weight of the armature. This suggests a convenient way of isolating many machine defects.

A whole article might be written on commutator slotting. The best practise in commutator slotting consists in undercutting the mica about 3/64 in. below the surface of the commutator. It is of extreme importance that great care be exercised in slotting a commutator to see that all the slots are free from strips or particles of mica flush with the commutator. It is not advisable to use lubricant or artificially lubricated brushes on a slotted commutator as the lubricant may get into the slots, collect dirt and cause short circuits between bars. On slow-speed machines where the peripheral speed is not sufficient to throw out particles of dirt the commutator slots should be blown out or scraped out at regular intervals. On a slotted commutator a brush with no abrasive action may be used and will result in long life of commutator and brushes. A non-abrasive brush or a self-lubricating brush does not necessarily mean a soft brush. In fact one of the hardest brushes manufactured in this country has been adopted as standard on slotted commutators by two of the four largest manufacturers of motors and generators, in this country, and is rapidly being adopted by the other two.

Heating of the commutator on a machine may be caused by any form of sparking, short-circuit currents, friction of brushes, high brush pressure, too low brush pressure causing high contact loss, dirty commutator, overloads, too small commutator, resistance of windings, loose connections, eddy currents and hysteresis. As the ultimate capacity of a machine depends on allowable temperature rise it is important to prevent heating wherever possible.

Rapid wear of commutator may be due to abrasion by the brushes, presence of gritty dust, or any form of sparking.

Short life of brushes may be due to sparking, glowing, or mechanical wear caused by high brush pressure, dirt, high mica or a rough commutator.

OUTSIDE ELECTRICAL CAUSES

Outside electrical causes of commutation trouble may be briefly stated as overloads, line surges, and cross currents between two or more machines running in parallel. Where the angular speed of a reciprocating engine varies greatly, surges may occur due to a slight reduction in speed of motors on the circuit when the voltage is low and a consequent rush of current when the voltage reaches its maximum. It may be impossible to locate surges or cross currents without the use of an oscillograph.

OUTSIDE MECHANICAL CAUSES

If an armature is mechanically unbalanced severe vibration may occur especially if run at high speed. This may produce flat spots, unbalanced electrical conditions, loosening of commutator bars and other serious troubles.

If the machine is on unstable foundations, similar troubles may be experienced due to vibration of the entire machine. In this class may be placed crane motors and similar machines which are however usually designed with this factor in view.

Poor belt lacing or uneven gears may produce a vibration or strain with the same results.

The pound of a reciprocating engine direct-connected to a generator sometimes causes such a serious vibration that the brushes are thrown slightly from the commutator, causing sparking and flat spots.

In this paper no attempt has been made to guide the operator in the selection or testing of carbon brushes, or to discuss the effects of characteristics of carbon brushes, but the writer hopes to have the opportunity of presenting another paper on this subject.

To be presented at the 306th meeting of the American Institute of Electrical Engineers, Cleveland, O., March 18 and 19, 1915, under the auspices of the Industrial Power Committee.

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(*Subject to final revision for the Transactions.*)

FRACTIONAL HORSE POWER MOTOR LOAD

BY BERNARD LESTER

ABSTRACT OF PAPER

In this article the author outlines the broad and increasing use of fractional horse power motors and the chief causes for the advance in popularity of motor-driven machines. The success in this field of motor application has been largely due to the perfection of a reliable and simple single-phase motor. The development in the design and construction of the single-phase motor is traced from its origination to the present time, and the operating characteristics of the commoner types of single-phase motors are described and illustrated by the use of speed-torque curves. The correct application of small motors is of utmost importance and requires a careful analysis of motor characteristics, the characteristics of the driven machine and of the supply circuit, with the limitations of each. The author deals particularly with the characteristics of the split-phase induction motor, which is used so extensively, and points out the functions of the centrifugal clutches when employed as a component part of this motor. A reference diagram is presented which is of service in applying small motors.

IN TECHNICAL literature very little space has been devoted to the discussion of fractional horse power or small motor load. The subject presents certain difficulties of approach perhaps on account of the close association of the commercial and engineering aspects, which cannot easily be divorced from one another. Furthermore, there is a tendency on the part of the engineering profession to consider, since the power producing units are so small and they are applied to such ordinary devices or machines, that the problems met in applying these motors are not strictly those which should concern an engineer. The purpose of this paper is to show briefly the extent of this rapidly growing field, and that in it real engineering problems exist which deserve most careful analysis.

When we consider that few motors were used in the industrial field prior to 1890, we realize, in a measure, the rapidity of the growth of the industry, but it is not until we classify the industrial field of motor application, and see what has been done in the va-

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rious industries, for example, in the steel mills, paper mills, textile mills and machine shops, that we can realize the development of motor application and can fully account for its growth. During the last ten years the field for the use of fractional horse power motors has increased enormously and many new devices have become available commercially. Typical examples of small motor applications can be found in residences, stores, offices and work shops. This list varies from motors used to drive vacuum cleaners, washing machines, meat and coffee grinders, and sewing machines, to those used in portable drills, railway signals, and the most delicate laboratory instruments.

There have been three principal causes for this development in the small motor field:

1. Efficiency engineering in every field of endeavor has brought to the mind of the public the realization of the saving that can be accomplished in time, labor and money by operating small appliances electrically.

2. Wide distribution of central station circuits, primarily for the purpose of lighting, have greatly increased the possible field for the use of small motors.

3. The performance of the small motor as a reliable source of power, and its proper application, have established the confidence necessary to encourage the investment of time and money in the development of the industry.

Savings in time, labor and operating cost by the use of small motor-driven machines can best be illustrated by reference to several very common small motor applications. In the dwelling, the small motor-driven washing machine, vacuum cleaner, ironing machine and sewing machine shorten the time required to do the work, and materially decrease the amount of manual labor required, besides increasing the quality of the work and the convenience with which it is done. In the office, motor-driven calculating machines, and machines for addressing, sealing and stamping mail matter or tying packages, are now becoming common, on account of the fact that they in the aggregate save a large amount of time on the part of the office force, or in reality increase the productive labor of the individual. In the blacksmith's shop, for instance, motor-driven forge blowers have taken the place of the old cumbersome hand-operated bellows. The store or meat market is now often equipped with a meat grinder, meat slicer, coffee grinder or coffee roaster. These make possible economies in the preparation of products for sale.

It will be noted that in all these cases the success of the device depends upon one or more of the three general features possessed by the small motor, *i.e.*, simplicity in starting and stopping, portability, and continued operation without frequent attention.

The remarkable extension in central power station lines in cities and suburbs needs no further comment here, other than to point out that the majority of small motor-driven machines are of such capacity and characteristics that they are suitable for connection to lighting sockets.

Since single-phase alternating-current distribution is so largely employed for lighting and consequently is available as a supply for small motor-driven machines, the development of a simple, reliable and efficient small single-phase motor has had a large share in the growth of this industry. Single-phase motors of the series, repulsion or induction type, or some modifications or combinations of these principal types, have been largely used.

Series Motor. The series-wound single-phase motor, due principally to its varying speed with change in torque, has a limited application. Obviously it can only be safely used where the load is rigidly connected to the driving shaft of the motor and where large variations in speed are permissible with variations in load. This type of motor is very successfully used with fans, where the fan is attached to the motor shaft, and is used for exhausting or supplying air, as in the case of most fan type vacuum cleaners or forge blowers. Also for portable electric tools, in which case the power is turned off when the tool is not in actual service. Its use, however, is limited to these or similar applications. A great advantage in the series-wound motor, when especially constructed, is that it can be operated upon direct current or alternating current of most commercial frequencies, and the same voltage, with speed-torque characteristics sufficiently similar to produce results generally satisfactory in motors of small capacity. Obviously, there is a great commercial advantage in a motor-driven device that can be operated either on alternating current or direct current.

The single-phase repulsion motor, which is a modification of the series motor, possesses in general the same limitations in regard to its speed-torque characteristics, as the series motor. However, without load it does not attain the same dangerously high speed. Since the brushes are short-circuited the universal feature, *i.e.*, the possibility of operation upon alternating-current or direct-current circuits, does not exist.

Induction Motors. The single-phase induction motor possesses a speed-torque characteristic in which the speed holds practically constant under a varying torque and is excellently suited for the large majority of small motor-driven machines, provided a means is supplied to bring the rotor or secondary element of the motor up to a speed at which the inherent torque produced by the motor is sufficient to accelerate the load.

The split-phase induction motor is by far the most common type of single-phase motor used in fractional horse power sizes. Since in its development the most difficult problem has been in overcoming the absence of starting torque in the simple single-phase motor, the principal steps in this development will be mentioned.

The first split-phase self-starting motor was developed by Tesla and was used for driving small desk fans, but was not employed generally for power service. Several years after this, about 1893, single-phase induction motors of larger capacities were developed and used, but since there was no device for starting the motor, it had to be started by hand;—and like any polyphase induction motor when connected to a single-phase circuit, and operated on one phase only, would run in either direction if started by some external force and accelerated to a point at which the torque developed by the primary of the motor upon the rotating element was sufficient to carry the rotor up to speed. The speed-torque curve of such a motor is shown in Fig. 1, curve *AD*. From 1893 to 1895 self-starting split-phase motors were designed with two windings in the primary, one of which was employed primarily while running, and the other only for the purpose of starting. A phase splitter consisting of a manually-operated external switch and resistance, connected the primary windings to the supply circuit, inserting resistance in the starting winding. A phase displacement in this way existed between the currents in the two windings, which exerted a torque upon the rotor in starting, the starting winding and resistance being manually cut out as soon as the

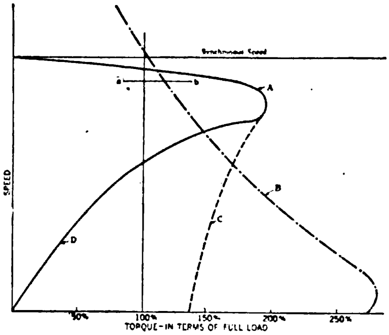
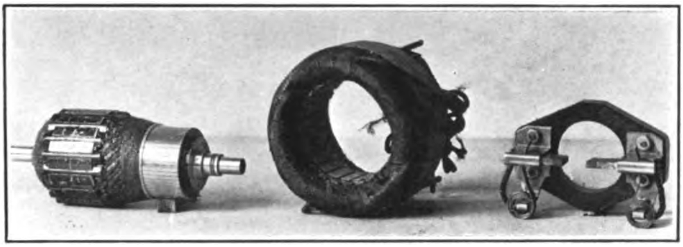
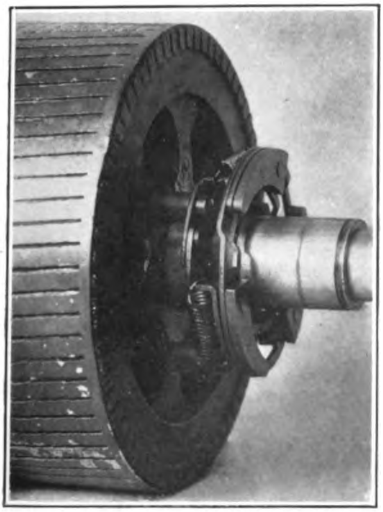


FIG. 1



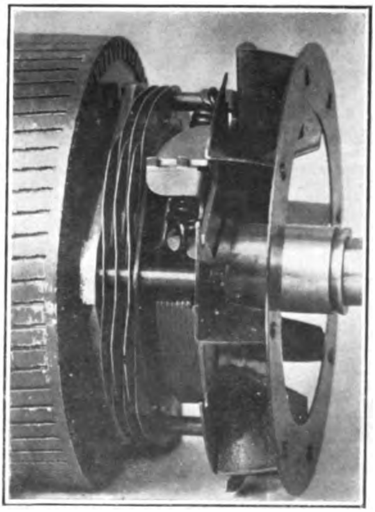
[LESTER]

Field, Armature, and Brush Rigging of High-Speed Series-Wound Universal Motor for Vacuum Cleaners and Electric Drills



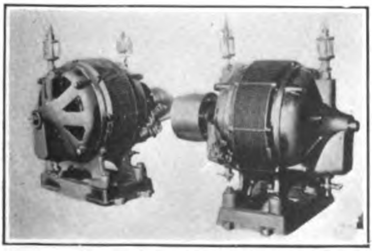
[LESTER]

Typical Automatic Switch of Latest Design, Used with Split-Phase Motor; Showing Centrifugal Element Mounted on Rotor



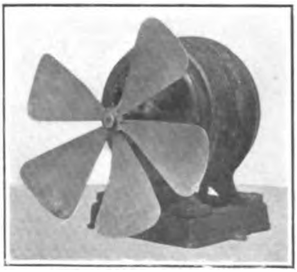
[LESTER]

Typical Multiple Disk Centrifugal Clutch of Latest Design Used with Split-Phase Motor



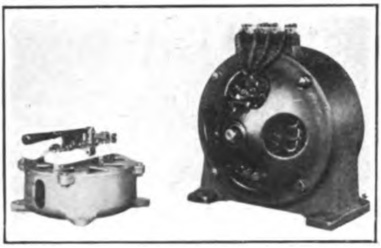
[LESTER]

1-h. p. Two-Phase Tesla Motors



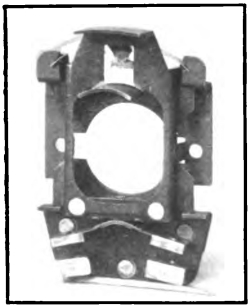
[LESTER]

Split-Phase Fan Motor



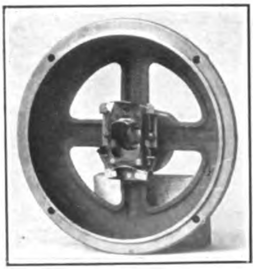
[LESTER]

¼-H.P. SINGLE-PHASE MOTOR WITH PHASE SPLITTER



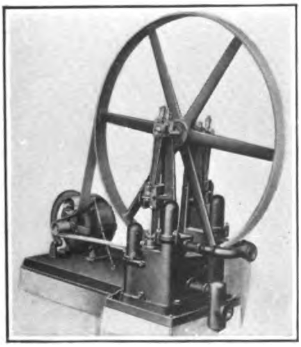
[LESTER]

TYPICAL AUTOMATIC SWITCH OF LATEST DESIGN, USED WITH SPLIT-PHASE MOTOR; SHOWING STATIONARY ELEMENT IN POSITION WHEN STARTING WINDING IS OPEN



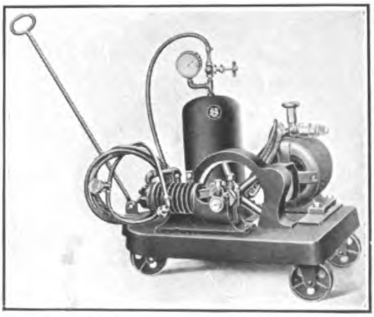
[LESTER]

STATIONARY ELEMENT OF CENTRIFUGAL SWITCH MOUNTED UPON MOTOR BRACKET



[LESTER]

MOTOR-DRIVEN HOUSE PUMP



[LESTER]

MOTOR-DRIVEN AUTOMOBILE TIRE PUMP

motor came up to speed. Somewhat later, motors were designed with which were used starting devices supplied with a condenser in place of a resistance. This device produced a greater angular advance in the phase displacement than was the case with the resistance starter. In this particular, therefore, a somewhat improved operating characteristic was obtained due to higher power factor of the motor,—the condenser remaining in the circuit while starting and running.

About 1898 single-phase induction motors were designed which started as series motors. The secondary winding was similar to that of a series motor, the commutator bars being short-circuited as the armature accelerated, after which the motor ran as an induction motor. Shortly after this an advantage was found in starting as a repulsion instead of a series motor, since the motor so constructed could be connected externally for use either upon 110- or 220-volt circuits. Motors designed in accordance with this principle are now widely used, especially in sizes above ½ h.p. An automatically operated centrifugal governor within the rotating element, short-circuits the commutator bars. Fig. 1, curve *B*, shows the speed-torque characteristics of such a motor while starting, in approximately the relative position to the induction motor, curve *AD*. The light line *ab* represents the speed at which the motor automatically switches from a repulsion to an induction motor.

Another development in the split-phase motor was in the use of an external clutch or clutch pulley. Due to the difficulty in obtaining in the earlier designs sufficient starting torque to enable the motor to be used for other than accelerating very light loads, centrifugal clutches were used which allowed the rotor and shaft to accelerate to a point at which a liberal torque was exerted by the rotor, at which point the clutch took hold and applied the load to the motor. Within the last few years marked improvements have been made in the design of split-phase motors. Sufficient starting torque can now be obtained without the use of a centrifugal clutch, for many classes of small motor service. A light, high-resistance starting winding in addition to the running winding is used. Fig. 1, curve *AC*, shows a typical speed-torque curve of a no-clutch split-phase motor of recent design. This starting winding is cut out by means of a very simple and reliable centrifugally operated switch placed within the motor, at a speed slightly below full load. The centrifugal clutch when used is of simple construction and is placed within the motor, the rotating element revolving upon the shaft until its speed reaches a predetermined point at which the clutch takes hold.

Various modifications have been made in the repulsion motor, intended to make its speed more nearly constant with varying loads, and also improve its power factor, by means of extra brushes on the commutator and auxiliary windings in the primary.

Since so many motors of one particular size and type are used, designs must be adapted for economic quantity manufacture and uniform performance consistent with such apparatus. Furthermore, since motors of special mechanical and electrical characteristics are often required, standard designs must be adapted to provide for such modification without a complete redesign of the motor. Fractional horse·power motors must be neat and attractive in appearance since they are used in the home, office or shop in connection with, or as a part of, a machine which is usually highly finished. Lightness of weight and compactness of construction are of considerable importance, for many small motor-driven machines are of a portable or semi-portable character. Quiet operation is always desirable and often absolutely necessary in cases where these motors are used for the operation of musical or talking machines. In the last few years it has become common practise to design direct-current motors with full-load speeds corresponding to those of 60-cycle alternating-current motors. Furthermore, for equivalent ratings in alternating-current and direct-current motors similar mechanical characteristics have been adopted, so that either an alternating- or a direct-current motor can be mounted in identically the same place in relation to the driven machine, thus simplifying the construction of the motor-driven machine.

Small motor applications fall into four thoroughly well defined classes, depending upon the length of the operating period and the variation of the load while in service, *i.e.*:

1. Motors operating continuously, with approximately constant load; for example, ventilating fans and forge blowers.
2. Motors operating continuously with varying load; for example, sign flashers and most adding machines.
3. Motors operating intermittently, with constant load; for example, coffee grinders and most automatic piano players.
4. Motors operating intermittently, with varying load; for example, household washing machines and ice cream freezers for household use.

It is interesting to note that small-motor engineers encounter almost identically the same problems as those of the engineer applying larger industrial motors, in so far as cycles of operation and speed-torque requirements are concerned. For instance, in the application of small motors to washing machines with wringers, the wringer is the limiting feature, taxing the motor with sudden peak loads. This application may well be compared to that of a motor-driven rolling mill. The motor-driven meat grinder compares closely with the motor-driven pulp mill beater, and the coffee grinder with the rock or stone crusher. In the design of high-speed motors for fan-type vacuum cleaners, the problems closely parallel those of the high-speed turbo blower.

Hundreds and even thousands of motors of one particular type and size may be applied to a particular type and size of driven machine, consequently, a very careful analysis should be made to secure the correct drive. Failure may come when operating conditions cease to be ideal, should a motor of insufficient margin of safety with regard to the essential electrical and mechanical characteristics be employed, and the expense of such failure cannot well be estimated when we consider that these small motor-driven machines are scattered broadcast. In the interests of economy, however, an abnormal margin of safety is objectionable. The question of the selection of the proper characteristics is largely, therefore, a consideration of limiting conditions of operation. The following general points should be considered:

Variation in the essential electrical and mechanical characteristics of duplicate motors, incident to their manufacture in quantities.

Variation in the value of torque required to start and power to operate duplicate driven machines, incident to their manufacture in quantities.

Variations in the characteristics of the circuit on which the motors are to operate, such as variations in voltage, frequency or both.

In applying split-phase motors, aside from the general characteristics outlined elsewhere, special attention must be given to those characteristics of starting torque, pull-out or maximum torque and temperature rating. The starting torque varies approximately as the square of the impressed voltage, consequently any reduction in the voltage of the circuit at the motor produces more than a proportional reduction in torque. Furthermore, the starting current of split-phase motors materially exceeds the full load running current. This factor, in addition to light wiring or insufficient transformer capacity, often results in a reduction in starting torque of the motor in the average commercial installation. Good practise in small motor application provides that the motor should be able to start the driven machine when the impressed voltage is as low as 20 per cent below the rated voltage. A centrifugal clutch is often incorporated in the design of the motor not only to insure an ample starting torque and reduce the effect of the current taken during starting, principally by cutting down the time during which it is taken, but also to provide an element of flexibility in the case of a machine rigidly connected to the motor. The clutch will slip in the event of sudden or extreme overload, thus protecting the combined unit.

Fig. 2 will give an idea of the comparative values of the current and its duration taken by split-phase motors during starting. These curves are oscillograph records. Curve *A* represents a motor without centrifugal clutch, driving a generator, and curve *B* is for a motor of equivalent capacity and speed, equipped with a centrifugal clutch, operating under similar conditions. The latter motor is supplied with a different starting winding, being permissible where a clutch is used. It should be noted that rulings prohibiting the use of single-phase motors upon lighting circuits, based upon the amount of current taken by the motor while starting, are misleading when expressed in terms of full-load current taken by the motor. For example, though the starting current of a $\frac{1}{2}$-h.p. motor may be only three times as great as the full-load current, its value may exceed that of a $\frac{1}{6}$-h.p. motor, even though the starting current taken by the latter may be five times its full-load current. It seems reasonable that such rulings should specify in amperes the permissible current which motors may take, corresponding to the established voltages.

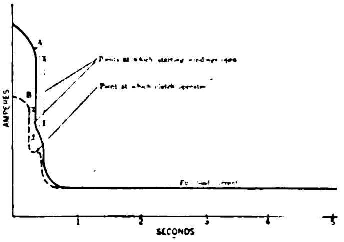
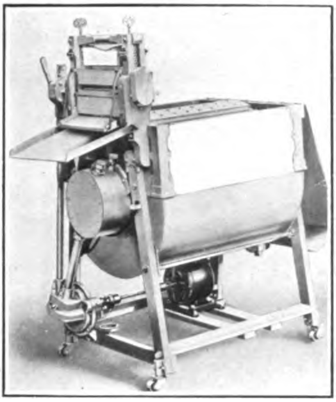


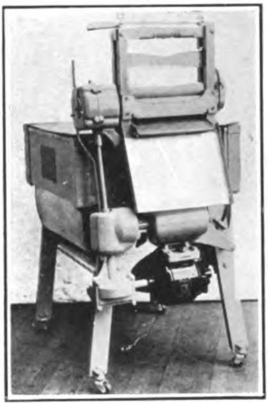
FIG. 2

The pull-out or maximum torque of the motor must obviously be sufficient to take care of any peak loads to which the motor may be subject in driving the machine, even at voltages somewhat lower than the normal rated circuit voltage.



[LESTER]

MOTOR-DRIVEN WASHING MACHINE



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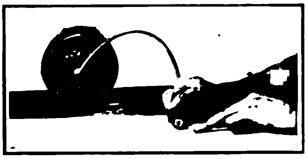
MOTOR-DRIVEN WASHING MACHINE



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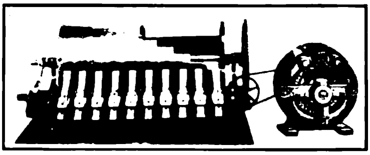
MOTOR-DRIVEN ERASING OUTFIT



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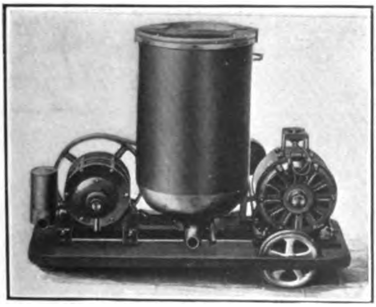
MOTOR-DRIVEN SIGN FLASHER



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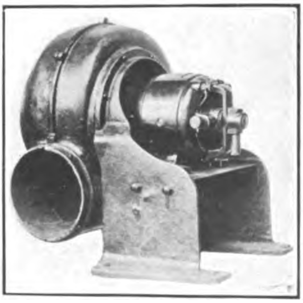
MOTOR-DRIVEN VACUUM CLEANER



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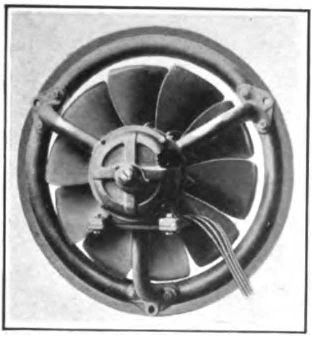
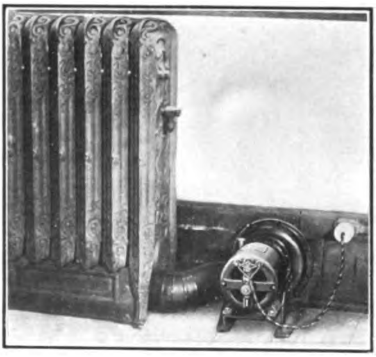
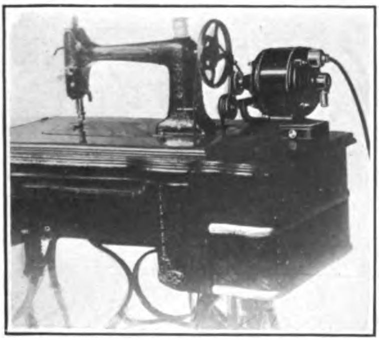
MOTOR DRIVEN BLOWER



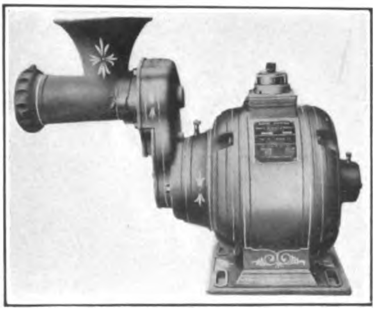
[LESTER]
MOTOR-DRIVEN EXHAUST FAN



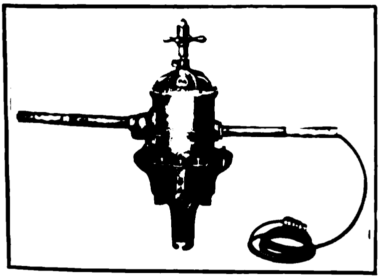
[LESTER]
MOTOR-DRIVEN VENTILATING OUTFIT



[LESTER]
MOTOR-DRIVEN SEWING MACHINE



[LESTER]
MOTOR-DRIVEN MEAT CHOPPER



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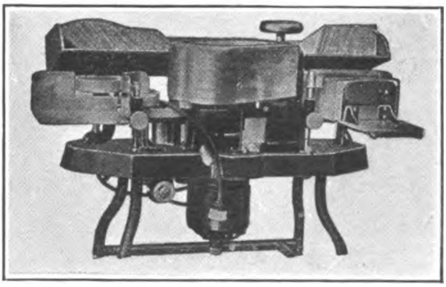
MOTOR-DRIVEN DRILL



[LESTER]
MOTOR-DRIVEN MAILING MACHINE

Many small motor-driven machines are not ordinarily called upon to operate continuously, but only for short intervals, with prolonged periods of rest intervening between operating periods. Obviously in these cases intermittently rated motors may be employed. However, unless the cycle of operation is well defined by practise, it is well to use a motor so rated that it will run the machine continuously without attaining a dangerous temperature. Sometimes the machine may be left running by mistake. Small motors of commoner designs and capacities will attain their maximum temperature in from two to five hours. Commercially it is not permissible with most small motor-driven machines, particularly those in domestic service or in stores and offices, to employ motors so rated that they will attain a temperature as high as the insulation will safely stand, for the motor becomes appreciably hot to the touch and creates suspicion.

The starting torque and pull-out torque of fractional horse power motors are usually measured in ounce-feet. The diagram shown in Fig. 3 (which is here reduced in size) has been prepared covering the various characteristics of fractional horse power single-phase and polyphase motors and is useful for purposes of reference. The following illustrations will indicate how it may be employed in small motor application work.

Knowing the Horse Power and Speed at Full Load, to Determine Full-Load Torque. For example, find the full-load torque of a $\frac{3}{4}$-h.p. motor running 1700 rev. per min. at full load (1800 rev. per min. synchronous speed). Find the intersection of the vertical line through 1700 rev. per min. with the curve marked $\frac{3}{4}$ h.p. (560 watts), and horizontally opposite this intersection at the left is the torque, 36.5 oz.

The Starting Torque and Maximum Running Torque can be found by multiplying the full load torque by the proper constants. For example, if the starting torque of this particular motor is 1.5 times the full-load torque, its value is $1.5 \times 36.5 = 55$ oz. Likewise if the maximum running torque of the motor is 2.5 times the full load torque, its value is $2.5 \times 36.5 = 91$ oz. These constants must be determined from the characteristic curves of the individual motor.

The Horse Power at Maximum Torque can also be determined from the curve if the speed is known. For approximate results the slip of small split-phase induction motors at maximum torque can be taken at 15 per cent. In the case of the above motor

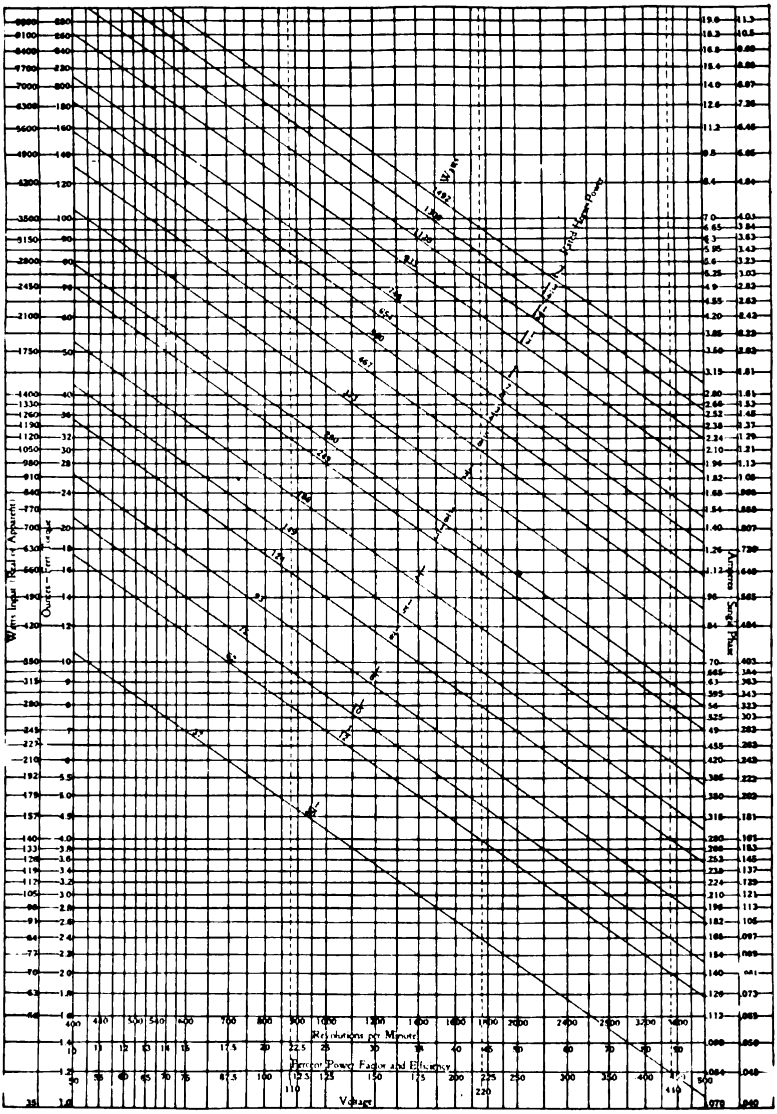


FIG. 3—CHART FOR DETERMINING RELATIVE CHARACTERISTICS OF SMALL INDUCTION MOTORS

For current in two-phase motors, take half the value indicated for single-phase motors.

the speed at maximum torque will therefore be approximately 1450 rev. per min. Find the intersection of the vertical line through 1450 rev. per min. with the horizontal line through 91 (oz. torque). This is near the line representing 1.5 h.p., which is the approximate power developed by the motor just before pulling out, or stalling.

Knowing the *Horse Power and Efficiency*, to find the *Real Watts;* for example, assume that the efficiency of the ¾-h.p. motor is 75 per cent. Find the intersection of the vertical line through 75 with the ¾-h.p. curve and horizontally across from this intersection is 746 watts.

Knowing the *Real Watts Input*, the *Power Factor* and the *Voltage*, to find the *Current per Phase* (or per terminal); for example, assume that the power-factor of the foregoing motor is 70 per cent and the voltage 220 volts. Locate the intersection of the 70 per cent power-factor vertical line with the diagonal representing 746 watts. The horizontal line passing approximately through this point represents 1050 watts apparent. Then from the intersection of the vertical line representing 220 volts with the diagonal representing 1050 watts, the horizontal line representing amperes is determined, namely 4.8 amperes, single-phase, or 2.8 amperes three-phase. The current per terminal in a two-phase motor is one-half that for a single-phase motor, and in this case would be 2.4 amperes.

To be presented at the 306th Meeting of the American Institute of Electrical Engineers, Cleveland, O., March 18-19, 1915.

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APPLICATION OF ELECTRICITY TO THE ORE HANDLING INDUSTRY

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Abstract of Paper

The paper gives a general description of the typical method of handling ore from the mine to the blast furnace, describing in a general way the machinery used in the different steps of the process. The general principles underlying the application of electric motors to these various types of machines are discussed, as well as the class of motors best adapted to the work and the considerations in regard to the power installation. The essential points to be considered are: 1, the determination of the shortest path over which the ore is to travel; 2, the determination of the characteristics of the loads in moving ore through this path; 3, the designing of the electrical equipment to carry these loads with minimum peak and maximum reliability, and 4, installation of a substation that will handle the load satisfactorily and most economically, considering both demand charges and the total kilowatt-hours used.

IN DISCUSSING the application of electricity to the iron ore handling industry it is the writer's intention to portray in a broad manner the nature of the problems which are encountered, and the general principles which should be kept in view. Detailed descriptions of the method of making the necessary calculations are now available in at least one of the later handbooks, and the electrical apparatus used for this class of work is fully described in the publications of the various manufacturers. It can easily happen, however, that the electrical engineer may lose sight of one or more of the points described herein, or that the purchaser of an ore handling plant may find himself saddled with an equipment for which the cost of power is unduly high.

Before describing the correct methods of applying electrical apparatus to ore handling machinery it will, perhaps, be best to give a brief description of the types of such machines as are in general use. The typical course of the ore from the mine to the blast furnace is as follows, this description applying particularly to the business as it is carried on in the Great Lakes district:

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After being mined in the upper lake region, the ore is carried in special hopper-bottom cars to one of the nearby shipping points, where it is dumped by gravity into large bins. These bins are connected to the hold of the vessel by means of spouts, so that loading is accomplished simply and in a very short time. The vessel then carries the ore to one of the ports on Lake Erie or Lake Michigan, where its cargo is taken out by means of large unloaders and is either placed on railroad cars or is stored in a stock pile for future use. After being loaded on the cars the ore is carried to the point of ultimate consumption, where it is usually unloaded by means of a car dumper. At this point two general schemes of handling the material may be used, the first consisting of a movable car dumper which travels along one side of a stock yard, into which it dumps the ore, and the second consisting of a fixed car dumper which dumps each freight car into an electrically propelled transfer car having gates in the bottom especially adapted to allow the ore to run out cleanly. In the latter case the transfer car deposits its load directly into the bins which serve the first skip hoist; or, if these bins are already full, the ore may be allowed to fall down an incline into the stock yard, from which it is reclaimed by means of a bucket handling gantry crane and placed in the furnace bins as it is needed. In this paper the discussion will be limited to the operations of unloading the boat at the dock and the unloading, stocking and reclaiming of the ore at the blast furnace.

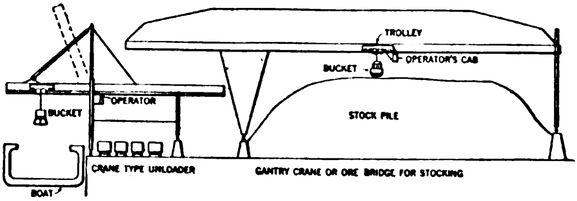

FIG. 1

Fig. 1 shows a side elevation of a dock equipped with one or more crane-type unloaders in combination with a rehandling gantry crane. The unloader is provided with a trolley which runs out over the hatches of the vessel; a clam-shell bucket is then lowered into the hold, and the loaded bucket is hoisted and trolleyed back either to a bin which feeds the freight cars, or to a space in the rear of the unloader, from which it is picked up by a bucket carried on the gantry crane trolley, and is placed in storage. From this storage pile the ore is eventually reclaimed by the stock pile gantry and is loaded on railroad cars. The crane type unloader is essentially the same as the stock pile gantry, and the principles which apply to one will apply to the other.

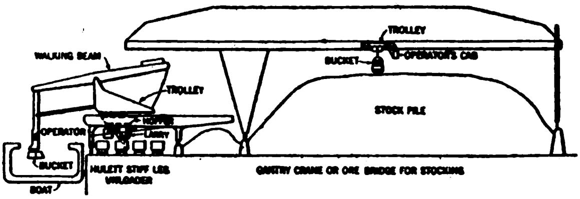

FIG. 2

Fig. 2 shows a Hulett unloader in conjunction with a gantry crane. In this type of unloader the bucket is suspended from a walking beam by means of a stiff structural leg, the operator riding directly above the bucket. This leg is held steady by means of an equalizer and may be rotated at will. The walking beam is carried on a large trolley which moves the loaded bucket back over a bin, into which the ore is dumped. From this bin the ore is fed as desired into a larry car, which carries it either to a point above an empty railroad car or else deposits it on the ground in the rear of the unloader, there to be cared for by the gantry crane.

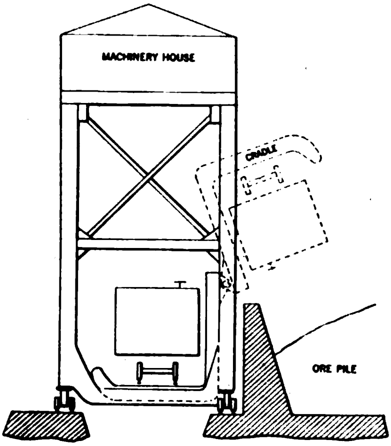

FIG. 3

Fig. 3 shows the end elevation of a movable car dumper.

With this type of dumper the car is pushed up a short incline by means of the locomotive until it rests on the L-shaped rotatable member. When this member is turned over, the contents of the car slide down a chute into the stock pile, the car being held in place by means of counterweighted clamps. The empty car is then rotated back into its former position, from which it is displaced by the impact of a new car. The machinery for operating the L-shaped member or cradle, and also for producing the longitudinal motion along the track, is located in the house at the top of the dumper.

Fig. 4 shows a side elevation of a fixed car dumper. The car is dumped in the same way as with a movable dumper, but with this type of machine it is necessary to haul the loaded cars up an incline and onto the cradle by means of what is known as a "mule," which consists of a small carriage running on a track between the freight car rails. This mule may be lowered into a pit in the bottom of the incline, from which it emerges after the loaded car has passed over it. The machinery is generally located in a house beneath the incline on which the mule operates.

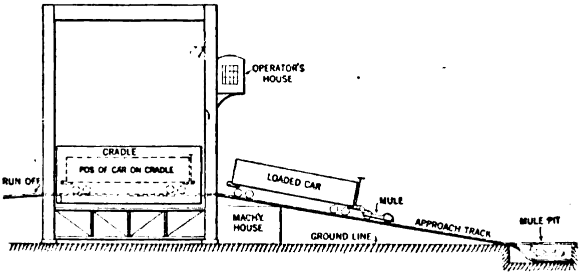

Fig. 4

The gantry crane for reclaiming the ore at the blast furnace is usually of the same general type as that used at the dock, except that when its capacity is small and its span is short, both the operating mechanism and the operator may be located on a fixed part of the bridge, the ropes for handling the bucket being carried out to a small trolley which is little more than a number of sheaves mounted on a carriage.

In considering the problems to be dealt with it will be found that the forces encountered consist either of gravity, acceleration or friction,—the latter being understood to be the force ultimately overcome by the mechanism and not the incidental friction in the train of gears. Both the gravity and friction loads produce a similar effect upon the motor, except that in the former case the motor must resist the force of gravity when lowering by means of dynamic braking. In both cases, however, the tendency is for the mechanism to run at a constant speed as soon as the starting resistance in the armature circuit has been cut out. When acceleration begins to be a considerable part of the total load while starting, conditions become changed, especially in the case where a series wound motor is used. If the motor torque required while short circuiting the resistance is greater than the torque required by the final load, it is evident that at the instant when all the resistance is cut out the motor torque is very much larger than is necessary, and will therefore tend to speed up the load until it reaches a point of equilibrium. Where the original accelerating force is high compared to the final force, this process of speeding up may consume a very considerable part of the total time of the trip.

It may be of interest to make a few simple calculations which will show to what extent the force of acceleration must be reckoned with in the various motions of an unloader or gantry crane. The most important motions of these machines consist of the bucket hoist, the trolley travel and the longitudinal travel. Taking first the hoist, we may assume a maximum speed of 300 ft. per min. or five ft. per sec., which is greater than is usually used. It will hardly be necessary to accelerate the bucket in less than two seconds; the acceleration A will therefore equal $5 \div 2$, or 2.5 feet per sec. per second.

If the weight of the load is W, then the force of acceleration

$$= F_a = \frac{W}{g} \times A = 0.078\ W$$

While neither the flywheel effects of the armature or of the hoisting mechanism have been considered, yet their inclusion would not add very greatly to the required force of acceleration, which is seen to be unimportant compared to the gravity load. For the same reason retardation, if accomplished in a reasonable time, will not add very greatly to the dynamic braking load incident to lowering, unless the lowering speed is allowed to become excessive.

Trolley speeds may vary from 200 ft. per. min. for a Hulett unloader to 1200 ft. per min. or even higher, for high speed gantries having very long spans. Since with a trolley mechanism it is essential to get under way as quickly as possible, the relation of the acceleration force to that of wheel rim friction may be stated as follows:

Using W as the weight of the combined trolley and load, and a value for A of 2.5 ft. per sec. per second, (which experiments by the writer seemed to indicate as a maximum value considered comfortable by the operator), then

$$F_a = \frac{W}{g} \times 2.5 = 0.078\ W$$

The average wheel rim friction load may be roughly taken as 25 lb. per ton. Therefore,

$$\text{Friction force} = F_f = \frac{25}{2000} \times W = 0.0125\ W$$

By combining these two equations it will be found that

$$F_a = 6.2\ F_f$$

It is obvious that motors for handling loads of this type must have a very high peak capacity, and in case they are of the series-wound type the final speed of the mechanism will very greatly exceed the speed attained when the last section of resistance is cut out.

To determine the distance traveled and the current consumption at any instant, for a trolley mechanism driven by a series-wound motor, it is necessary to use a step by step method, assuming a series of constantly decreasing torque values on the characteristic curve of the motor, thereby determining the average available accelerating force for each increment, and consequently the time necessary to accelerate through the increment of speed. This method has often been fully described, but a brief outline of it may be of interest.

After assuming the trolley gearing, a constant between torque and force and between trolley ft. per sec. and armature rev. per min. must be worked out. T_1, which represents the average torque during acceleration, will be obtained by combining friction torque T_f and acceleration torque T_{a1}, the former being calculated from the wheel rim friction force F_f and the latter being derived from acceleration force F_{a1}, which in turn should be calculated from the highest value of acceleration that the operator can comfortably stand. By the use of the characteristic curves of the motor the value of the motor rev. per min. can be found, from which can be derived the trolley velocity V_1. Then, if A_1 is the value which has been chosen for acceleration while resistance is being short-circuited,

$$\text{Time} = t_1 = V_1 \div A_1$$
$$\text{Distance} = D_1 = 1/2\, t_1 \times V_1.$$

T_2 is next arbitrarily assumed on the motor curve together with its corresponding value of V_2. Then,

$$T_{a2} = T_2 - T_f,\ F_{a2} = kT_{a2},\ \text{Average } F_a = \frac{F_{a1} + F_{a2}}{2},$$

$$\text{Average } A = \frac{G \times \text{Average } F_a}{W}$$

Also,

$$T_2 = \frac{V_2 - V_1}{\text{Average } A},\ D_2 = \frac{V_2 + V_1}{2} \times T_2$$

In this way a curve may be plotted with time as the abscissa and speed and the distance traveled as the ordinates. Horse power and amperes may also be included by reading the motor curve for the various values of T.

Retardation should be taken at about the same value as was figured for the initial acceleration during the short-circuiting of the resistances.

In considering the longitudinal motion, which is used quite infrequently, it is evident that rapid acceleration is not at all important. The longitudinal speed will seldom exceed 120 ft. per min. or two ft. per sec.; if this speed is taken as the value attained when the resistance is all cut out, and if the latter operation consumes four seconds, the value of A will be 0.5 ft. per sec. per second, which will give a value for F_a of approximately 0.0155. Allowing 40 pounds of wheel rim friction per ton, owing to the fact that the ratio of axle to wheel diameter is generally large and the lubrication not always of the best, F_f will have a value of $0.02W$. Therefore,

$$F_f = F_a \times \frac{0.02}{0.0155} = 1.29\ F_a$$

As a matter of fact it is usual to provide a longitudinal travel motor capable of propelling the machine against a 10-lb. wind pressure—a load which will usually equal the friction load or even exceed it by 50 per cent. During ordinary operation, therefore, there will be plenty of motor capacity for acceleration, but the peak to be carried when starting against a heavy wind should be carefully investigated.

For movable car dumpers, unloaders and gantry cranes of short span, the longitudinal travel motor is almost invariably mounted in a house somewhere along the bridge structure, the power being transmitted to at least half of the wheels of each truck by a system of spur and bevel gears. In this case the operator is often located close to the mechanism, which is usually supplied with a mechanical brake which may be released only by the application of the operator's weight. A brake of this nature can be applied gradually, thus avoiding shock to the mechanism when it is brought to rest.

On long span gantry cranes it is often desirable to place one or more motors on each truck in order to avoid the expense and the friction losses incident to the long squaring shaft used with a single motor bevel gear drive. In a case of this kind it has been found that there is little tendency for one end of the crane to run ahead of the other, no matter what type of motors may be used. Separate controllers are of course necessary for each end of the crane, and safety devices should be provided to prevent the structure from being twisted in case one end gets too far ahead of the other. In a case of this kind the motors must be supplied with solenoid brakes, which should preferably be of a kind in which the full braking force is not applied suddenly.

In the foregoing calculations on acceleration no consideration has been given to the flywheel effect of the armature. Fig. 5 shows a curve in which the flywheel effect [*Wt.* × (rad. gyr.)^2] of a number of armatures has been plotted against their horse power. The values given are obtained by averaging the actual values for several lines of standard d-c. mill motors. A curve of this kind may be useful at times for making preliminary calculations.

The best plan for estimating the effect of the armature inertia is to translate the weight of the armature into terms of the moving load. Since in the case of a trolley motion the speed of the motor is constantly varying, a gear ratio of some sort must be assumed before any calculations can be made. As the equivalent weight of the armature is given at one ft. radius, the speed of this weight will equal two rev. per min.; and since by the assumption of a gear ratio there has been established a definite relation between motor rev. per min. and load feet per min., the armature weight may be stated in terms of load weight by multiplying it by the square of its equivalent speed and dividing by the square of the load speed. Owing to the fact that when figuring acceleration, the accelerating force required at the load must be divided by the efficiency (expressed as a decimal) in order to allow for the losses in gearing, it will be necessary to multiply the equivalent motor weight by the efficiency before adding it to the load weight, since the accelerating force for the armature does not have to be transmitted through the gearing. With the usual type of trolley used in ore handling machinery, the acceleration of the trolley motor armatures may amount to ten per cent of the total. When calculating the capacity of the motor for any kind of work with which the engineer is not familiar, it is well to look into the matter of armature acceleration.

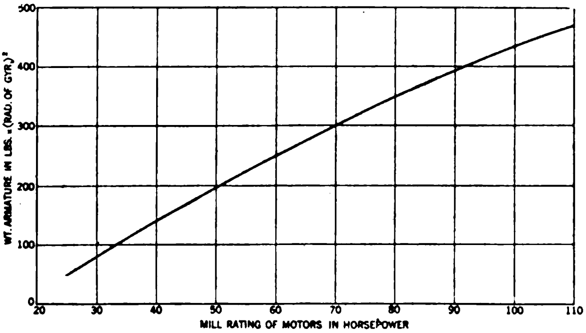

FIG. 5—COMPOSITE CURVE OF FLYWHEEL EFFECT OF THREE DIFFERENT MAKES OF MILL MOTORS

It has been seen that in all trolley motions acceleration is the main feature, while in longitudinal traverse motions it is less important, and in hoisting motions it is of little moment. Transfer cars in this respect may be classed with the trolleys, while the cradle turning motions of the usual type of car dumpers are hoists. The mule haulage of a fixed car dumper is a combination of the two types of load, since the acceleration of the car to a speed of anywhere from 200 ft. to 400 ft. per minute is a considerable item. This acceleration, however, takes place before the car gets well onto the grade, so that it is not ordinarily combined with the gravity load. It may be added that this mule haulage motion is one in which the writer has found that the flywheel effect of the armatures is a matter worth figuring, owing to the fact that the mule is run down the grade at a much higher rate of speed than normal and must be retarded very rapidly as it enters the mule pit.

Referring again to the subject of hoists, the engineer should give due consideration to the question of lowering, which in any bucket handling device is likely to require a very considerable negative force to be exerted by the hoisting mechanism. The question of dynamic braking has been gone into so often and so thoroughly that the writer will merely say that it is practically indispensable for lowering large buckets and the like. The dynamic braking current should be calculated in order to ascertain its heating effect on the motor. This calculation should be made by the use of the characteristic curve of the motor, it being borne in mind that the motor torque, and not motor horse power, is the thing to be first obtained. This torque will, of course, be reduced by the gearing losses instead of increased as in hoisting.

The speed of lowering may be increased considerably over the hoisting speed by increasing the resistance in the armature circuit, but care should be taken that the armature voltage does not rise very much above its normal value,—a point that may easily be checked after the dynamic braking current has been calculated. While the current produced by the armature may be returned to the line, yet this requires a more complicated form of controller than is usually used, and is moreover generally practicable for one speed of lowering only. Up to the present, the great effort in the ore handling industry has been to secure reliability rather than any nicety of current economy and in the future reliability will still be the main consideration, since delays may possibly tie up a ship or even a blast furnace.

In entering upon the consideration of an ore handling problem, the electrical engineer must have a fairly definite knowledge of how much ore it is required to handle per hour, per day and per year. The hourly rate will affect the gearing and also the peak load; the daily rate will affect the heating of the motors; while the yearly rate will determine the number of kilowatt-hours on which figures for power are to be based.

After determining the minimum time in which the average round trip or cycle of a given machine is to be made, the engineer should draw a mental picture of the shortest path for the ore to travel. The hoist and trolley motions should then be geared so that when operating as nearly simultaneously as possible they will carry the ore through this short path. In other words, it is poor economy to install a hoist motor which will raise the load to the required height long before the trolley has reached the end of its travel. A rather more common error is to gear the trolley motion entirely too high, so that it is necessary to hoist for a considerable length of time before starting to traverse the trolley. Some trolleys are so improperly geared that they may cover almost half their average travel before the resistance is all cut out of the armature circuit. This is probably due to the fact that some designers persist in believing that the nominal speed of a series motor prevails under all load conditions. Gearing of this kind overloads the motors, produces high peak demands on the source of power, and is very unsuitable indeed where there are many short motions to be made.

Having determined the proper gear ratios for carrying out the desired cycle of operation successfully, the engineer should check up his motor by plotting a current curve. With enclosed motors the root-mean-square method may be used, taking the total time of the cycle as the divisor. This method is not strictly accurate, but has been found to be a good guide. The only scientific way that the writer has seen to determine the heating of an enclosed motor is one which has been recently brought out by one of the large electrical companies. With this method the radiating capacity in watts for each frame is given and curves are furnished showing the motor loss in watts for various loads. The average watts which must be dissipated by the motor for a given cycle can thus be determined.

With open type motors the root-mean-square method is also generally used for figuring the heating, but it should be remembered that this type of motor is more dependent on the rotation of its armature for heat dissipation than is the enclosed motor. The writer has been accustomed to estimate the equivalent value of the time when the motor is accelerating or retarding as being equal to two-thirds of the full-speed running time, the time at rest being taken as equal to about one-third of the running time, thus, if the cycle of operation of a given motor be 60 seconds, of which 30 seconds is consumed in running at full speed, 12 seconds in accelerating and retarding, while for 18 seconds the motor is at rest, then the total equivalent time will be 30 seconds plus 8 seconds plus 6 seconds, which equals 44 seconds. The latter value then would be used as the divisor under the radical in determining the r.m.s. current.

While mill motors are usually rated on the horse power which they will develop for one hour with a rise of 75 deg. cent., open-type motors may either be given their continuous rating at 40 deg. cent. or may have a nominal rating of about 50 per cent above their continuous capacity. The nominal ratings of motors afford a basis of comparison between similar motors of the same type, and give some idea of the commutating capacity of the motor. They are not particularly valuable in any other way, as it is the continuous heat dissipating ability of the motor which is essential for severe all-day operation.

With most ore handling machinery the limitations of space do not permit the installation of the ordinary open type motor; moreover the mill type of motor is generally preferable on account of its high momentary overload capacity and its sturdy mechanical construction. It will often be found, however, that an enclosed motor of this type, while in other ways ideal for the work, may have insufficient heating capacity for all-day service. In such cases, if the motor can be protected, a semi-enclosed type of frame may generally be obtained, which will give a greatly increased heating capacity. With machines of the car-dumper type where there is plenty of room in the machinery house, open-type three-bearing motors are commonly used.

After the engineer has plotted his current curves for each of the essential motions of his ore handling machines, these curves for one machine should be combined, showing the current input to the machine on its average cycle, care being taken not to include dynamic braking current. The current curves for the other machines should then be combined with the first one in order to find the characteristics of the load for the total plant. Where there are two unloaders at work the writer generally assumes that an average condition will be for one unloader to be a quarter of a cycle in advance of the other, this being a mean between the condition where the machines are in synchronism and where they are half a cycle apart. Due provision, however, must be made for handling an occasional exceptional peak due to simultaneous operation of the important functions.

Where there are a number of unloaders working together the writer generally figures that half of them may be in synchronism at the same time. This is a question to answer which the engineer must use his best judgment, combined with considerable patience in trying out various combinations of load cycles. It is obvious, however, that the peak loads of a number of machines will very seldom come at the same time; in such cases it is better to let the circuit breaker open than to provide the necessary equipment for handling such an unusual condition.

With an installation which obtains its current from the power house of a large steel mill, the question of peak load is not very serious. In the case of an isolated dock, however, a complete generating station must be built, or else power must be purchased—and in both of these cases the form of the load curve is very important. It will usually be found that the public service corporations will supply power at a cost which is slightly under the cost of generating the power at the dock, if the proper allowances be made for depreciation, possibility of accidents, etc. Since purchased power is almost invariably in the form of alternating current, the possibility of using a-c. apparatus is a question that is always with us. Where machines of the type of the Hulett stiff-legged unloader are used,—and these machines unload most of the ore on the Great Lakes,—alternating current is out of the question. The Hulett machine owes much of its success to the fact that the operator is in close proximity to his work, and can gage distances to within a very few inches. Without the use of a delicate system of control, which is possible only with direct-current dynamic braking, this advantage would be largely lost.

For transfer cars, direct current is almost essential, since such cars are best propelled by railway or mine-type direct-current motors. An a-c. motor of similar size, even if designed for axle suspension, would hardly have sufficient torque to obtain rapid acceleration.

Bucket handling gantry cranes and crane type unloaders can use alternating current if their hoist motions are provided with dynamic braking. This dynamic braking is obtained by exciting one phase of the stator from a small low-voltage direct-current motor-generator set, the resistance in the rotor circuit being changed to obtain the various changes in speed. This system is not very reliable, however, as the dynamic braking torque depends very considerably on the proper combination of rotor speed and resistance, and is likely to be lost almost entirely if a too rapid retardation is attempted. The trolley travel motors are also not nearly as satisfactory, since all the acceleration must be obtained while short circuiting the starting resistance, whereas with a series d-c. motor this operation will probably bring the motor only up to half speed, the rest of the increase of speed being attained after the resistance is cut out. The a-c. trolley motor, therefore, may often be badly overloaded while starting, yet after acceleration it may be underloaded to such an extent that its power factor is very bad indeed.

The writer believes that a fairly successful a-c. car dumper may be designed, although it would cost more than a d-c. machine and would undoubtedly give more trouble. There might be cases, however, where the installation of such a machine would be justifiable, provided that the required rate of handling ore were not very high nor the continuity of operation very important.

It should be borne in mind that while mill-type motors may be obtained for 25-cycle circuits, the 60-cycle motors obtainable are all of the open type, requiring protecting from the weather. These motors should also be provided with an outboard bearing when their ratings exceed 25 horse power.

After a preliminary decision has been made as to whether alternating or direct current is to be used, the power contract offered should be carefully inspected. This contract will invariably provide a charge for each kilowatt of demand, this charge varying from one to two dollars per month. The way the demand is figured, however, varies quite widely with different power companies; with some it is the shortest peak which can be detected by a curve-drawing instrument, while with others it is the average of the load for the worst hour during the month. Other companies base their demand charge on the capacity of the transformers in the substation, but in this case they sometimes allow themselves the option of installing a curve-drawing instrument, determining their charge by a certain per cent of the indicated peak for a given time if such peak shows a higher monthly charge than could be calculated from the rating of the transformers.

Where the ore handling machinery is operated by a-c. motors there is little that can be done toward reducing demand charges, but if a substation with motor-generator sets or synchronous converters is installed, there is a possibility of diminishing these charges under certain conditions. When the demand is based on a peak lasting five seconds or less, a synchronous converter plant with a flywheel balancer is usually applicable. This flywheel balancer is a shunt wound d-c. machine which is connected across the busbars, and which sometimes acts as a motor and at other times as a generator. It has coupled to one end of its shaft a laminated flywheel running at very high speed. When the peak load comes on, the regulating apparatus strengthens the field of the balancer so that it generates direct current into the busbars until its speed —and consequently that of the flywheel—has been reduced to the value corresponding to the strengthened field. After the peak load is over, the field is automatically weakened and the balancer gradually brings the flywheel up to its former speed.

The synchronous converter substation, provided where necessary with a flywheel balancer, will generally be found to be cheaper and more economical of power than a motor-generator station, the flywheel equipment in both cases being equal. The motor-generator set, however, may have the advantage in certain cases. For one thing, the direct voltage may be more easily controlled. The principal advantage, however, is in cases where the demand charge is based upon the rating of the connected apparatus. Since the size of the d-c. machine will almost always be governed by its commutating capacity, it is evident that the a-c. apparatus supplying it with power may have a much smaller rating than would be supposed, provided that it is protected from excessive peaks. Now, a comparatively small flywheel will prevent the motor of the motor-generator set from pulling out of step, and even if the speed falls off considerably a voltage regulator can be used at the direct-current end if a steady voltage is necessary. An installation of this kind is, therefore, worthy of consideration under the proper conditions.

The meter charge for power furnished is often graduated, decreasing as the quantity of power consumed increases; in some cases the rate for the last gradation may be as low as 0.5 cents per kw-hr. and the combined peak and meter rate may be less than one cent per kw-hr. While it will usually be found that any economics in power consumption affect the cheaper rather than the higher power rates, still in certain instances such economies may tend to reduce the demand charge. For instance, series parallel control will reduce the starting peak of a trolley mechanism or a transfer car very considerably, and may also be profitably employed in mechanisms such as those of car dumper cradle hoists or mule haulages. This system is not always adapted to bucket hoists, as there is usually one independent motor and controller for each of the two parts of cable by which the motion of the bucket is controlled. In case series-parallel control should be used with a hoist motion, care should be taken to choose a type which passes from series to parallel smoothly. This point is particularly applicable where conpound-wound motors are used, owing to the back e. m. f. which is always present in the moving armatures of such motors.

In summing up the question of choice of motors for ore handling equipment, preference should be given to the mill type where the room is restricted and where momentary overloads are severe and often repeated. Enclosed crane motors are satisfactory in the smaller sizes for less severe and less frequent service, while open type motors are excellent for service of the car dumper type where heating is quite a factor but where overloads are not very severe. As stated before, either railway or mine-type motors may be used with transfer cars, but if the latter are installed they should probably have a better margin of safety than the former, as they are very compactly built. Mine motors are, however, very convenient in some cases, because they are designed for slow speed, high torque work.

With regard to the type of field winding, experience has shown that the series-wound motor is admirable for almost all classes of ore handling machinery. Occasionally it is necessary to use a compound-wound motor where there is danger of a runaway, but the shunt field, especially in the restricted space available in a mill motor, is a distinct point of weakness with regard in insulation.

It is the practise at the present time to install contactor type control for every motion of any importance whatever. This type of control pays for its increased cost, not only in decreased depreciation and maintenance, but also because the operator need pay so little attention to it that he is free to concentrate his mind upon his work.

With hoist controllers it is usual to give the operator at least one power point in the lowering direction so that he may pay off slack in case the negative load is absent. The other steps may all be dynamic braking. In any case, the armature and field should at all points be included in some kind of a closed circuit with one another so that there will be no possibility of a runaway.

Trolley controllers usually do not include dynamic braking, and may or may not have series parallel control, although the use of two or more motors on large trolleys is universal in order to secure sufficient traction. If dynamic braking is desired, the motor fields should be separately excited so that the motors will act as shunt generators. If the connections are such that the motors are turned into series generators, not only will the armatures have to be reversed for dynamic braking to take place, but the braking itself will be very uncertain. At low speeds it may entirely fail to materialize, while at high speeds it may be over-severe. Probably a good air brake equipment on the trolley is superior to dynamic braking, unless the operator is located at a distance from the mechanism. It should be remembered also that it is quite safe to "plug" the trolley motors if a point of high resistance is available to limit the consequent rush of current.

Motor-driven apparatus combined with contactor-type control is particularly suited for automatic travel limitation. Systems of this kind vary from the simple cutting off of power, which is all that is necessary for a bucket hoist, to the slowing down by armature shunting and the subsequent acceleration, which are automatically obtained, in some car dumpers, just as the mule engages the loaded car. Dynamic braking, if desired, may also be obtained automatically by means of a limit switch. Where slow speeds are desired with light loads, armature shunting is generally used. One point, however, is often rather unsatisfactory, as it is likely to be too violent during the first part and too weak toward the end of retardation. If series-parallel control with compound-wound motors is used, half speed may easily be obtained, whether the load is light or heavy; but the control should be such that resistance is inserted momentarily into the armature circuits during the transition, so that the current generated back into the line will not be excessive.

Solenoid brakes are used almost universally in ore handling machinery where there is any kind of a gravity load. Possibly the best friction surface of such brakes consists of some one of the several asbestos compounds which may be obtained, although iron shoes are often used. Solenoid brakes are generally mounted on the armature shaft of the motor, but in very important mechanisms where it is feared that there is a chance of the motor pinion failing, the brake wheel may be placed on the countershaft. The series type of winding is preferable as far as strength of insulation is concerned, but is impracticable where the load is likely at times to decrease to a very low value. In such cases shunt winding should be used, a separate contactor on the controller generally being necessary to handle its circuit.

While there are several lines of excellent motors on the market, detail improvements are still possible in some directions. The writer's experience is not nearly so extended as that of one engaged in maintenance work, but the results of his observation would indicate that the following points are worth watching:

Insulation of fields, especially where shunt windings are used.

The mica in the commutator, which in many cases should be undercut.

The construction of the armature spiders and the bracing of the rear ends of the armature coils, which are subjected to great strains where motors are allowed to over-speed and are then suddenly retarded.

In spite of the use of commutating poles, sparking at the commutator is not uncommon. Where this occurs from extremely rapid changes in loads, the trouble may possibly be that the solid cores of the commutating poles do not respond as quickly to the magnetomotive force as do the laminated cores of the main poles. In other cases, sparking and commutator heating may be traced to the vibration of the gears. The use of cut herringbone gears in such cases often leads to a remarkable improvement in commutation. Indeed, it is likely that the future will see a very wide use of these gears in the ore handling industry. When properly set up their life is long, their efficiency high, and noise is almost absent. The makers of these gears recommend that the pinion be mounted between two independent bearings, with a connection to the motor shaft by a flexible coupling. While this is doubtless the ideal method, yet in many cases where these gears have replaced spur gears, without any other change having been made, they have given satisfaction. Pinions should be set up, however, with due regard to a possible magnetic longitudinal pull of the motor shaft.

With regard to electrical troubles which may be experienced with an ore handling plant as a whole, the writer has found that most of them come from a piecemeal method of design which often prevails. The purchaser of machinery for a dock, for instance, will sometimes buy the unloading equipment from one concern, the stock pile gantry from another, while he will put in the substation apparatus and the contact rails himself. In this way the various parts do not always match as best they should, and in some cases the substation is not of a design which is well adapted to keeping the power bills at a minimum. A consideration of the foregoing will perhaps make it apparent that the following points are essential to a well-designed plant:

The calculation of the shortest path through which the ore is to travel.

The determination of the characteristic of the loads incident to moving the ore through this path at the proper number of trips per hour.

The provision of electrical equipment capable of carrying these loads with a minimum peak and a maximum of reliability.

The installation of a substation, if power is to be purchased, that will handle the load satisfactorily and will also be best suited to the power contract, considering both demand charges and the total kilowatt-hours to be used per year.

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THE FACTORS INVOLVED IN MOTOR APPLICATIONS

BY DAVID B. RUSHMORE

THE work of applying electricity to industrial operations consists in properly combining the motor, controller and machine to be driven. This involves the characteristics of all three and a number of other features which are concerned more or less in the particular situation.

The following is a list of some of the factors involved and is intended to be used as an introduction to a discussion on the individual features concerned.

SUMMARY OF THE FACTORS INVOLVED

1. Alternating or direct current available?
2. Voltage and frequency (if alternating current)? Possible variations in same?
3. Capacity of generating station and lines? Other load on systems? (This information is required for determining effect of starting).
4. Description of machine to be driven? Continuous or intermittent service? Can intermittently operated machines be arranged as to not operate simultaneously? Limited speed?
5. Method of drive. Group vs. individual. Direct connection (Size of coupling, rigid or flexible, insulated? Shaft extension, sub-base, etc.)
   Belt drive (Size of pulley, distance between pulleys, outboard bearing, belt tightener?)
   Chain drive (Size of pinion).
   Gear drive (Size of pinion).
   Friction drive (Is motor to be started light and clutch thrown in when motor is up to speed?)
6. Load conditions.
   Continuous?

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Cycle-duty, in which a definite cycle repeats itself with more or less regularity, the machine stopping between each cycle?

Varying-load duty, in which more or less definite cycles are repeated, but motor runs continuously?

(Load diagram required during a complete cycle of operation. This gives the maximum horse power, length of load on, time off and friction load).

Can any parts of cycle be varied with benefit?

Variation in load caused by change of conditions, such as decrease in the head on a centrifugal pump. Allowance must be made in the motor size to take care of such contingencies.

Future conditions? It is possible that the load on the motor may be soon increased? Motor speeded up? Flywheel effect required?

7. Starting conditions.

Frequent starting, stopping or reversing?
(Number and time off?)
Time of acceleration?

Does load on motor increase as it comes up to speed?

8. Speed.

Is close speed regulation essential?
Constant speed?
Adjustable speed?
Varying speed?
Multi-speed?
Speed range required?

At reduced speed, is horse power output reduced in proportion to speed (*i.e.* constant torque)? If not, give the proportion.

9. Control.

Hand or automatic?
Remote?
Overload or no-voltage release?
(Time setting?)
Limit switches?
Brakes?
(Mechanical or electrical?)
Stopping of large motors?

10. Conditions of location.
    - Dust, moisture, acid fumes, inflammable material, high temperature, etc.?
    - Ventilation?
    - Space conditions?
        - (Method of mounting motor, access for repairs, etc.)
    - Safety arrangements?
    - Insurance regulations?

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LINE DISTURBANCE CAUSED BY SPECIAL SQUIRREL-CAGE AND WOUND-ROTOR MOTORS WHEN STARTING ELEVATORS AND HOISTS

BY J. C. LINCOLN

ABSTRACT OF PAPER

The author examines the cause of line disturbances in starting hoists and elevator motors and draws comparison between the performance of wound-rotor motors and squirrel cage motors of a special design for elevator service. Diagrams are given showing graphically the current required for each type of motor to produce a given torque, and the method of control required by different types of motors is also considered. The performances of both types of motors at maximum, ordinary and light loads are compared.

THERE IS a widespread opinion among the engineers of many public service companies furnishing electric power, that wound-rotor motors are inherently superior to squirrel cage motors for hoist and elevator drive, and this is shown by rules issued by some of the larger companies restricting the amount of maximum current that may be supplied to squirrel-cage motors, while the restrictions imposed on wound-rotor motors are much less rigid. The object of such regulations on the part of public service companies is to minimize line disturbances and provide as good voltage regulation as possible under the actual conditions of service.

The object of this paper is to examine the causes of line disturbances in starting hoist and elevator motors and to determine, if possible, if the preference for wound-rotor motors for such service is well founded.

Hoists and elevators are so generally constructed with a worm to which the motor is directly connected, engaging a worm wheel to which the load is attached, that only this type of mechanism will be considered in this paper.

There is a rather remarkable lack of exact knowledge among the builders of hoists and elevators as to the amount of torque actually required to start the load as compared to what would

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be required if there were no friction. The amount due to friction is assumed by many of the elevator builders to be 50 per cent. To put this in concrete shape, let us assume that an elevator builder has received a contract for an elevator in a district where a-c. power only is supplied, which has to lift a load of 3000 lb. at a rate of 100 ft. per minute. He will figure the weight of the car and provide counterbalance for it, and then, in addition, will provide counterbalance for part of the load. Usually about 40 per cent of the load is counterbalanced. To put it another way, the ordinary load is assumed to be 40 per cent of the maximum, and at this load the weight of the car and load together equals the counterbalance, so the power required by the motor at this load is zero, except for friction. At maximum load, this will give a net load to be lifted of 1800 lb. and the net work done will be 1800 × 100 = 180,000 ft-lb. per minute or 5.45 h.p. The elevator builder would double this for friction, making 10.9 h.p. and then, if he had figured on a close margin of profit, would probably use a 10 h.p. motor. He knows that all motors are capable of some overload and he trusts that the overload capacity of the motor, and the fact that his particular machine has "very little friction", will enable him to lift the maximum load. Suppose the motor has a maximum torque corresponding to twice the normal rating, then starting efficiency would have to be

$$\frac{5.45}{2 \times 10} = 27 \text{ per cent in order that the 3000 lb. may be lifted.}$$

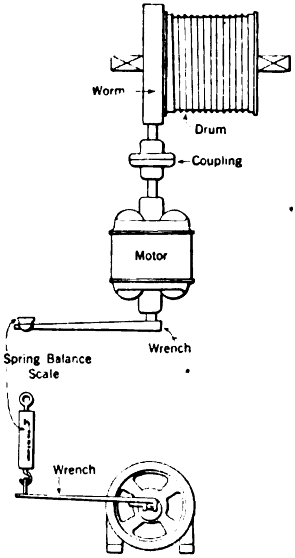

FIG. 1

An experience with a number of different machines built by a number of different makers shows that the starting efficiency is from 15 to 20 per cent. The starting efficiency is determined as follows:

Fig. 1 shows an elevator in outline, the winding drum, the worm under oil, the coupling, the motor, a pipe wrench fastened to an extension of the motor shaft (or to the worm shaft near the coupling if there is no shaft extension on the motor), a spring scale or balance attached to the handle of the wrench, say 24 in. from the center of the motor shaft. Full load is now put on the elevator and the brake lifted off, the spring balance is lifted until the motor shaft moves in such a direction as to lift the load. This test is repeated at say ten or twelve points in a revolution of the motor shaft and the maximum lift on the spring balance is noted. From this maximum is deducted the dead weight of the wrench handle, and the balance is the net force required to start the load. Let us assume that the synchronous speed of the motor is 900 rev. per min. that the net lift was 88 lb. The horse power developed at 900 rev. per min. would be

$$\frac{900 \times 88 \times 2 \times 2\pi}{33{,}000} = 30.2.$$

The useful work done at 900 rev. per min. is 5.45 h.p. The required starting torque corresponds to 30.2 h.p. at 900 rev. per min. The starting efficiency in this case is then $\frac{5.45}{30.2} = 18.1$ per cent. If the manufacturers of ordinary elevators would multiply the net work done by the elevator by five or six instead of two, they would come closer to the actual torque required to start the load with a new hoisting equipment.

So far only starting efficiency has been considered, for experience has clearly shown that once the load is started a much smaller amount of torque is required to lift it. The reason for the greater torque required to start the load over that required to lift it is probably due to the fact that there is an opportunity for the load to squeeze the oil from between the worm and worm wheel and from the bearing that carries the end thrust of the worm, so that at the instant of starting the surfaces are dry and the metallic surfaces are in direct contact with each other, while after starting, oil is carried between the surfaces and during the lift the metallic surfaces have a film of oil between them, thus greatly lessening the friction.

In order to obtain an intelligent conception of the best type of motor for operating motors and hoists, it will be necessary to know approximately the character of the load. We know that the starting torque is higher than the running torque. The question is, how much higher? Inquiry among the manufacturers of gears and elevators and worm drive automobiles failed to give an answer to the question and it was decided to answer it by direct experiment on a freight elevator.

The elevator selected has been in use for two and a half years and has a full load capacity of 3000 lb. It has a steel worm and cast iron gear, the worm being entirely under oil. The starting torque was found by loading the car with 3000 lb. and following the method shown in Fig. 1. The running torque was found by carefully measuring the input in watts and deducting the watts lost in the stator windings and stator iron. The difference was, of course, delivered to the rotor, which taken in connection with the synchronous speed, determined the torque, The net torque after deducting the weight of that part of the wrench handle carried by the spring balance was 45 lb. and the radius 3 ft. 9 in. The corresponding torque at one ft. radius is then $45 \times 3.75 = 169$ lb. The power supplied to the motor in order to lift the load showed a variation of at least 40 per cent, a little over 10 kw. being required to lift the load on some of the up trips and over 14 kw. being required on other trips with the same load. Let us take 12 kw. as the average power input. The *IR* loss in the stator coils and the iron loss in the stator iron equals at this current approximately 1800 watts. There will be therefore, 10.2 kw. or 13.7 h.p. delivered to the rotor. The torque at one ft. radius corresponding to 13.7 h.p. equals 80 lb. The running torque is therefore, about one half of the starting torque on this particular hoisting equipment which had been in use two and a half years.

The gear ratio and drum diameter on this machine were such that at synchronous speed of 900 rev. per min. the load would be lifted at 70 ft. per minute. The counterbalance was a little short so that the net load lifted when 3000 lb. was put on the elevator was about 2100 lb. The useful work done then was $\frac{2100 \times 70}{33,000} = 4.45$ h.p. The power delivered to the rotor was 13.7 h.p. The running efficiency is therefore $\frac{4.45}{13.7} =$ 32.5 per cent, and the starting efficiency about half of this, or about 16 per cent. I believe both the starting and running efficiency of this machine are low on account of the cast iron gear, and that the starting efficiency of this machine after two and a half years of use is about what is obtained by a hoisting equipment with a new bronze gear.

The voltage drop in any a-c. circuit is due to two factors, first the drop due to ohmic resistance, depending on the amount of current and the resistance of the transformer and connecting wires. The other source of drop is due to the inductance of the transformer and leads. In this paper it will be assumed that the drop in the leads and in the primary supply are equal to the drop in the transformer. A company manufacturing a standard line of three-phase transformers has given me the following figures:

	Power Factor				
	60%	70%	80%	90%	100%
5 kw.	23%	24%	23%	22%	1.7 %
7.5 "	21 "	22 "	21 "	20 "	1.55 "
10 "	22 "	22 "	21 "	20 "	1.45 "
15 "	25 "	25 "	24 "	21 "	1.35 "
20 "	26 "	26 "	24 "	22 "	1.35 "

It will be seen from this table that in transformers of 15 kw. and above, the drop at 70 per cent power factor is nearly twice what it is at 100 per cent. At 71 per cent power factor, the real watts and the quadrature watts are equal. It is clear from this table that the drops are proportional to the current, and further, the drops increase as the power factor decreases.

It will be necessary then to examine the characteristics of wound-rotor motors and the special squirrel cage motors referred to in this paper to determine the currents required to give the required torque and the power factor of the currents.

By what is known as a Heyland circle diagram it is possible to show graphically the currents required by an induction motor to produce a given torque, the maximum torque the motor is capable of producing and the power factor under the different conditions.

Fig. 2 is the circle diagram of a slip-ring motor, in which *oy* is the vertical axis, and quantities parallel to this axis may be read as true watts, or as torque, when multiplied by the proper constant; *ox* is the horizontal axis and quantities parallel to this axis may be read as quadrature watts; *oa* represents in length the current taken by the motor running light. The angle *yoa* is the angle of lag of the current behind the voltage, and *od* shows the current that will be taken when the short circuited rotor is blocked or cannot revolve. The current that would be taken if there were no ohmic resistance in the rotor is represented by *oc*. The length of the line *df* represents the torque delivered by the motor when all resistance is cut out of the rotor circuit. If resistance equal to nearly twice the resistance of the rotor is inserted into the rotor circuit, the current taken by the motor when blocked is reduced to *oc* but the torque is increased to *cg*. If the resistance in the rotor circuit is increased to about 6.5 times that of the rotor, the current taken by the motor is decreased to *ob* and the torque changed to *bj*.

IDEAL THEORETICAL OPERATION OF WOUND-ROTOR MOTORS

In theoretical ideal operation, a high resistance is inserted in the rotor circuit and the primary current would be represented by *ob* at the instant the current is thrown on. The motor is supposed to start and if it does, the increase in speed of the rotor acts like an increase in the resistance in the rotor circuit so far as the primary current is concerned and the primary current decreases as the rotor speed increases. The slip is very large on account of the large external secondary resistance and after the rotor has attained a proper speed, part of this resistance is cut out and the total resistance is reduced from 6.5 times to about twice the resistance of the rotor. Reducing the resistance of the rotor circuit reduces the slip in the rotor, and the speed is therefore raised. Cutting out this resistance increases the current in the primary but the speed of the rotor is supposed to be high enough when the resistance is cut out so that the primary current does not rise above *ob*.

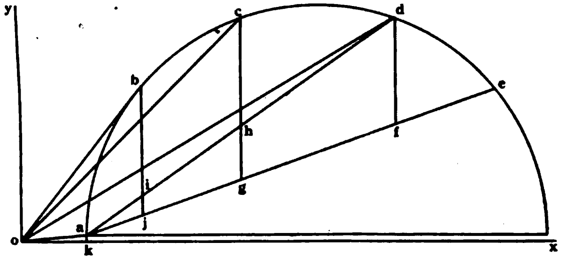

FIG. 2

After a further increase in speed, the remaining resistance of the rotor is cut out and the rotor runs at nearly synchronous speed to the end of the trip. It will be noticed that the torque per ampere in the starting condition corresponding to *ob* is high, the torque corresponding to the length of the line *bj* and the primary current to *ob*. Further, the power factor of this current is good, the angle *box* being large and therefore, its cosine is small. It is upon the supposition that slip-ring motors operate in the manner just described that they are preferred or required by many power companies.

THE ACTUAL OPERATING CONDITIONS

Let us examine the actual operating conditions. A majority of elevator controllers are of the series relay type and are so designed that the second step of resistance will not be cut out until the motor starts, and the line current, therefore, is reduced by the rotation of rotor to less than a predetermined maximum. The reason for this is to secure the ideal cycle described above. Unfortunately, the motor may have to lift it's maximum load at times, and therefore, the resistance must be so adjusted that the motor will *be sure to start*. Therefore, instead of the first step having a high rotor resistance and a small primary current corresponding to *ob*, Fig. 2, the resistance must be adjusted at a much smaller value so as to give the primary current shown in Fig. 2, or *oc*, in order to give the maximum starting torque *cg*.

If the torque required to start the elevator is nearly equal to the maximum torque the motor will deliver, it will be necessary to adjust the secondary resistance to get the maximum torque, and therefore the primary current shown in Fig. 2 by *oc*. The torque per ampere with the primary current *ob* is 30 per cent higher than with the current *oc*. Further, it is likely that in adjusting the secondary resistance to give the maximum starting torque this resistance may be too low. If such an adjustment was made for the motor shown in Fig. 2, the current at starting might be increased from *oc* to *od* but the torque would be decreased from *cg* to *df*. The torque per ampere, as compared with the secondary resistance adjustment that gave the primary current *ob*, would be only a little over one-third. Further, the current *od* has a lower power factor than the current *oc* and only about half the power factor of the current *ob*. From the standpoint of the central station man, it is the possibility of bad adjustment when the controller is new and the probability of bad adjustment when the controller is old and worn, that constitute the great objection to the wound-rotor motor.

A SQUIRREL CAGE MOTOR DESIGNED ESPECIALLY FOR ELEVATOR AND HOIST DUTY

The above considerations induced the writer to design, several years ago, a special squirrel-cage motor for elevator duty. This motor has a rotor of very high resistance, and therefore the maximum or starting current is only one-third to one-half of what it would be with the ordinary squirel-cage motor. The torque at starting is about 85 or 90 per cent of the maximum torque the motor could deliver with a rotor having resistance to give the maximum torque. The characteristics of such a motor are shown in the larger circle in Fig. 3. The smaller circle in the same figure shows the characteristics of a wound-rotor motor with the same stator winding and the same number of slots in both stator and rotor. The line *bj* shows the maximum torque of 610 ft-lb. that could be obtained from the motor by a primary current *ob*. The line *ac* shows the actual torque that is obtained by the use of an extra high resistance rotor. The torque corresponding to primary current *oa* is *ac*, or 540 ft-lb. This is 88 per cent of the maximum obtainable torque. The torque per ampere with the primary current *oa* is however, about 30 per cent higher than it would be if a rotor of lower resistance were used and a primary current *ob* was obtained. With a motor of this construction it is impossible to obtain large currents at low power factors such as would result from an improper adjustment of resistance, or defect in the controller of the wound-rotor motor. The torque per ampere and the power factor at maximum current are always high. It will be seen that the maximum torque that can be obtained from this motor supplied with a wound rotor is 470 ft-lb. This would be obtained with a current *ok* which is greater than *oa*, and also of lower power factor. If a maximum torque of say 500 lb. was required it would

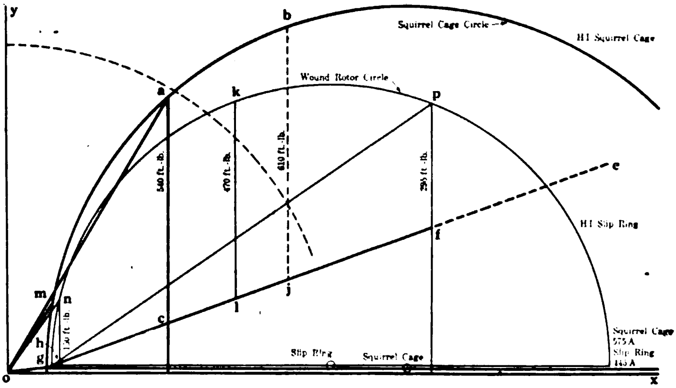

FIG. 3

not be possible to use a wound-rotor motor built with this size of frame and a larger frame would have to be used. In Fig. 4, the larger circle is a duplicate of the large circle of Fig. 3 and shows the characteristics of a squirrel-cage motor with a special rotor. This frame is designed for a 15-h.p. motor for continuous duty with a 35 deg. temperature rise. The smaller circle shows the characteristics of a wound-rotor motor of the next larger frame, rated at 20 h.p., for continuous duty at 35 deg. temperature rise. It will be seen that the maximum torque of the wound-rotor motor is practically the same as that of the squirrel cage; 625 and 610 ft-lb. repectively. Let us see how the two motors compare at the maximum torque of the squirrel-cage motor, 540 ft-lb. The line *oa* represents the primary current of the squirrel-cage motor, and *ob* the primary current of the wound-rotor motor required to produce the same torque of 540 ft-lb. The current *ob* is a little greater than *oa* and has a little poorer power factor.

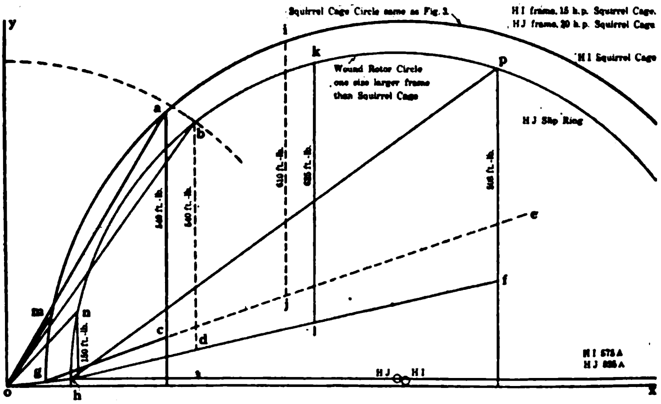
Squirrel Cage Circle same as Fig. 3.
H I frame, 15 h.p. Squirrel Cage.
H J frame, 20 h.p. Squirrel Cage
H I Squirrel Cage
Wound Rotor Circle one size larger frame than Squirrel Cage
H J Slip Ring
y
i
k
p
a
b
540 ft.-lb.
540 ft.-lb.
610 ft.-lb.
625 ft.-lb.
e
f
j
l
m
n
150 ft.-lb.
c
d
g
H J
H I
H I 575 A
H J 825 A
o
h
x

FIG. 4

To compare the two motors at light load, I have assumed that 150 ft-lb was the torque required of the motor to lift the ordinary load on the elevator after starting. Line *om* shows the primary current required by the squirrel-cage motor and *on* the current required by the wound-rotor motor. At ordinary loads, then, the wound-rotor motor takes more current and this current has a lower power factor.

Our examination, therefore, has shown that the special squirrel-cage motor is superior to the wound-rotor motor when both motors are required to produce the same maximum torque.

It is also superior when both motors are running at light loads. Let us consider, then, if there are any circumstances under which the wound-rotor motor would be superior to the special squirrel-cage motor.

If instead of using the standard series relay type of controller for the wound-rotor motor, a dash-pot type of controller was used, it is clear that if the load on the elevator and the required starting torque were small, the wound-rotor motor would start up with such a high resistance in the secondary circuit as to give a small primary current and much less than the maximum torque. Such an installation would start a light load with less primary maximum current than the special squirrel-cage motor, and if a greater torque was required, it could be obtained when the second step of resistance was cut out. Experience seems to show, however, that such a controller is not satisfactory in practise, for only a few are in use. There are serious objections to this type of controller, among which are the following:

(a) The time required to start the elevator after current is thrown on the motor will depend on the adjustment of the dash-pot and if this is properly adjusted for light loads, the motor will not start with heavy loads until one or more steps of resistance are cut out. Under usual conditions, this leads to an adjustment of the dash pot that will allow the steps to be cut out much too fast, or to an adjustment of the resistance such that the maximum load will be started on the first step of resistance. If the resistance is so adjusted, all the advantages of this type of controller over the series relay type are sacrificed, and any possible advantage of the wound-rotor motor over the special squirrel-cage motor is also sacrificed.

(b) The adjustment of a dash-pot will not remain constant: Changes in the temperature of the dash-pot will affect the adjustment, and the presence of dirt and corrosion will also affect it. These causes may be depended upon in time to so alter the time of operation of the controller that a change in the adjustment of the controller will have to be made. The great danger in such a change is that it will allow too rapid a movment of the controller. Such a rapid movement with light load on the elevator will not affect operation but if the maximum load is put on the elevator it is likely that the motor will pass through its position of maximum torque (see Fig. 2) before the motor has attained much speed and reach the condition represented by the primary current of Fig. 2, in which the torque is only about half the maximum, and in consequence the elevator would stall. This is the difficulty that the series relay type of controller eliminates.

A secondary advantage of the special squirrel-cage motor from the standpoint of the central station man is its more satisfactory service as compared with the wound-rotor motor and its controller. Experience has shown that nearly all the delays and troubles on wound-rotor motors are due to small repairs and adjustments on the controller, slip rings, brush holders and brushes. If the special squirrel-cage motor is used, the controller slip rings, brush holders, brushes and wound rotor are eliminated, therefore, the service is less liable to interruption. It is to the interest of the electric power station to have devices on its line that give no trouble; for the less trouble experienced, the more motors are installed and the more power is used.

CONCLUSIONS

(1) In a given installation, both the squirrel-cage and wound-rotor motors must be capable of lifting the heaviest load and therefore, must be capable of exerting the same maximum torque.

(2) If the standard series relay type of controller is used on the wound-rotor motor the maximum torque must be exerted on the first step, for sometimes the maximum load has to be lifted.

(3) If the same maximum torques are exerted by both types of motors greater starting currents are required by the wound-rotor motors than by the special squirrel-cage and these larger currents are taken from the supply lines at lower power factors.

(4) In lifting the ordinary load which is much less than the maximum, more current is required by the wound-rotor motor, and this current is taken from the lines at lower power factor.

(5) In order that the wound-rotor motor may start with less current than the special squirrel-cage motor, under any circumstances, a controller must be provided in which the steps of resistance are cut out in approximately equal time intervals. This is best accomplished by means of a dash-pot. Experience has shown the dash-pot controller to be subject to so many troubles that few of them are used.

(6) Elimination of the first cost, maintenance and troubles of controller and slip-ring motors, by the use of special squirrel-cage motors, will cause more motors to be installed on slow-speed elevators and hoists, and more current to be sold.

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ANSWERS TO SOME QUESTIONS ON ELECTRIC ARC WELDING

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Abstract of Paper

The paper contains a general description of the process of electric arc welding and discusses some of the general principles involved in this work. Some of the principal difficulties encountered in electric arc welding are described and comparison is made of its advantages over other methods of welding. The author concludes that there are very few cases of welding which cannot be more satisfactorily done with the electric arc than by any other means, provided the operator is sufficiently skillful. He also considers that less practise is required by opera ors to make successful electrical welds than is necessary with any other process. The paper concludes with some operating costs of different types of electric arc welding machines.

FOR A PROCESS of such great importance as arc welding, surprisingly little is known regarding it among many manufacturers who could apply it to advantage in their work. The available literature on this subject is very incomplete, and gives but little information to the man who might apply arc welding to his product. It is the object of this paper to consider the fundamental principles of arc welding of metals so that the manufacturer can decide for himself the following questions which may arise in connection with the work in his own plant.

1. What metals can be welded by the electric arc?
2. What difficulties are encountered in electric arc welding?
3. What is the strength of the weld in comparison with the original piece?
4. What is the cost of welding?
5. What is the function of the arc welding machine?
6. How does electric welding compare with oxy-acetylene and other similar methods?

There are many concerns that could use electric arc welding to great advantage but which are overlooking its possibilities because of insufficient knowledge in regard to it.

All metals can be welded. Any two pieces of metal which are brought into contact at their melting temperature will adhere so

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that they are no more liable to break at the point of junction than at any other point. This is a well-known property of all metals and the welding process, therefore, is very frequently applied. The electric arc is used in connection with the process merely as a heating agent, and this is its only function in connection with the process. It is superior to any other method of heating because of its ease of application and the economy with which heat can be concentrated at any given point by its use. There are no conditions in connection with arc welding to which these principles do not apply: viz., that metals at a welding temperature will adhere, and that the electric arc will most economically and easily furnish the heat to bring them to this welding temperature.

The difficulties which are encountered in welding are the following: Formation of oxide; expansion and contraction under heat; burning through.

In the case of brass or zinc, the heated parts will be covered with a coat of oxide before they come to a welding temperature. This zinc oxide makes it impossible for two clean surfaces of the metal to come into intimate contact. It follows that some method must be adopted for disposing of this oxide at the weld and allowing the two surfaces to be welded to come together without the possibility of oxide being included between them. This condition obtains in the welding of aluminum and of a great many alloys. In order to eliminate this coat of oxide it is usually necessary to puddle the weld, that is, to have enough of the metal melted at the weld so that the oxide is floated away from it. When this is done, the two surfaces which are to be welded are covered by a coat of melted metal on which the oxide floats, thus allowing two clean surfaces of metal to come together. This precaution, however, in case of steel, to which welding is applied to a greater extent than to any other metal, is not usually necessary.

Another difficulty which is encountered in the welding of a great many metals is their considerable expansion under heat which results in a corresponding contraction when the weld cools, so that internal stresses are introduced which in extreme cases will result in cracking the metal at or near the weld. To eliminate this possibility, it is necessary, depending on the shape of the piece, to apply heat either all over the piece to be welded or at certain points, so that the uneven contraction giving rise to internal stresses will be avoided. In the case of cast iron, it is often necessary to anneal after welding, since otherwise the welded piece will be glass hard on account of chilling.

Another difficulty with arc welding is that very thin pieces of metal which are to be welded together and which are not backed up by something to carry away the heat, are very liable to burn through, leaving holes where the weld should be. This difficulty can be avoided by backing up the weld with a metal face, or by decreasing the intensity of the arc so that the melting through will not occur. The practical limiting thinness of metal to which arc welding can be applied without metallic backing is approximately 22 gage, although thinner metals than this can be welded if the operator is very skillful.

The next difficulty with arc welding is the lack of skillful operators. Manufacturers in a great many cases look upon arc welding as being very complicated, and are very apt to become discouraged with the results of unskilled operators. They sometimes do not give the operators a chance to master the process before making up their minds that the method is not feasible. If the same point of view were held by manufacturers in regard to welding by means of the forge fire, blacksmithing would never have come to be practised, and a broken piece of steel would always remain a piece of scrap. It does not require anything like as skillful handling to make a good arc weld as it does to make a weld on an anvil, and there are very few electric welds that cannot be handled successfully by an operator of average intelligence with one week's instruction, although his work will become better in quality and finish as he continues to gain experience.

Next comes the most important question of all; that is, what is the strength of the weld? The answer is that the strength of the weld is equal to that of the metal of which the weld is made. It should be remembered, however, that the metal which goes into the weld is really a casting, and has not been rolled. This means that the strength of the weld would be equal to that of the same metal that is used for filling, if used in the form of a casting. For example, two pieces of steel could be welded producing a tensile strength at the weld of at least 50,000 lb. per sq. in. Higher tensile strength than this can be obtained by the use of special alloys for the filling material, or by rolling the weld. Tensile strength as great as mentioned will give a result which is perfectly satisfactory in almost all cases.

There are a great many welds where it is possible to build up, that is, to make the section at the weld a little larger than the section of the rest of the piece. By doing this, the disadvantage of the weld being in the form of a casting while the rest of the piece is in the form of rolled steel can be overcome, and the weld itself will be even stronger than the original piece.

The next question of importance to the man contemplating a new application of welding is, what is the adaptability of electric arc welding to my work in comparison with anvil welds, acetylene welds or some other method? This is somewhat difficult to answer comprehensively. There are no doubt some cases where the use of a drop hammer and a forge fire and the oxy-acetylene blow torch will make, all things considered, a better job than the use of the electric arc, although cases where this has been conclusively proved are extremely rare. The electric arc will melt metal in a weld for from 3 to 30 per cent of the cost of melting it with the oxy-acetylene blow torch, on account of the fact that the heat can be applied exactly where it is required, and in any amount that it is required.

Let us now consider some of the essential features of various types of arc welding machines which are in use. The three most important considerations in the design of the welding machine are: (1) the variation of the supply voltage as required by the arc; (2) power economy; and (3) conversion from alternating- to direct-current energy. It is practically out of the question to apply the alternating current to arc welding since one electrode must always remain positive. In arc welding by means of the carbon arc, the piece to be welded is made the positive electrode, while in welding with a metallic arc either the piece to be welded or the piece used as a filler may be made the positive electrode.

The voltage across the arc is a variable quantity depending on the length and temperature of the arc and the gases in it. With a carbon electrode the voltage will vary from 0 to 45 volts. With the metallic electrode the voltage will vary from 0 to 30 volts. It is therefore, necessary for the welding machine to be able to furnish the arc with a current which can be varied as required both in quantity and voltage.

The simplest welding machine is an ohmic resistance in series with the arc. This is entirely satisfactory except, in regard to the cost of current. By the use of resistance in series with the arc on a 220-volt supply circuit, from 80 to

90 per cent of the current is dissipated in heat in the resistance. Another disadvantage is the fact that most resistances will change with the temperature, thus making the amount of current delivered to the arc a variable quantity. There have been various methods devised for saving the power lost in the series resistance, and a good many machines designed for this purpose have been put on the market.

Practically all arc welding machines now in use consist of motor-generator sets, the motor of which is adapted to the existing supply circuit, and is direct connected to a compound-wound generator delivering current at approximately 75 volts. This current is applied to the arc in series with a resistance. It is evident that since the voltage across the arc will vary from 0 to 50 that from 75 to 25 volts must be dissipated in the resistance, although a considerable saving is effected over the use of a resistance in series with the full supply voltage. It is possible to construct a machine that will eliminate these losses by avoiding the use of a resistance in series with the arc. A machine of this kind will save its cost within a very short time, provided the welder is in steady use.

The following figures give the approximate cost of power for operating arc welding machines under average conditions, which are assumed as follows:

Cost of current, 2 cents per kw-hr.; metallic electrode arc of 150 amperes; carbon arc of 500 amperes; voltage across the metallic electrode arc 20; voltage across the carbon arc 35; supply circuit 220 volts direct current; a single resistance in series with the arc.

With the metallic electrode, the cost of energy will be 66 cents per hour. With the carbon electrode $2.20 per hour. If a motor-generator set with a 75-volt constant potential machine is used for a welder, the cost will be for the metallic electrode 25.2 cents per hr., and for the carbon electrode 84 cents per hour.

With a machine which will deliver the required voltage at the arc without the use of a series resistance the cost will be for the metallic electrode, 7.2 cents per hour, and for the carbon electrode 42 cents per hour. These figures assume that the arc is held continuously at its full value. This condition, however, is impossible in practise, and the actual load factor is approximately 50 per cent, which means that, as a welder is usually operated, the actual cost of operation will be about one-half of the amounts given above. It is evident, therefore, that it will not take very long to save the cost of a welding machine if all the power wasted in resistance could be saved.

Electric arc welding has not received the attention it deserves and large economies would probably result from its use in many metal working industries. Its adoption merits the serious consideration of all metal workers.

DISCUSSION ON "ELECTRICITY IN THE LUMBER INDUSTRY" (WHITNEY), SPOKANE, WASH., SEPTEMBER 10, 1914. (SEE PROCEEDINGS FOR DECEMBER, 1914).

(Subject to final revision for the Transactions.)

Mr. Scott: Mr. Whitney's paper is of particular importance to central station men because it shows that there is a field for prospective business open that is usually placed in the same class with steam laundries, that is to say, absolutely unapproachable. I have never dealt directly with any logging men, but have had occasion to attempt to sell power to a few sawmill men, particularly for small plants, none of very large capacity, and their main objection to motor drive is, first, they claim the first cost of the motor installation is excessive as compared with a steam engine; and, second, they say that the motors will not stand up to the work. Now, never having actually seen a drive of that kind I was not in a particularly advantageous position to refute their statements. Third, they say they must have steam anyway for their dry kilns and for their log-carriers, and therefore there is no particular advantage in putting in electric drive. And lastly, they say that they are forced by law to get rid of their waste; in most instances they are too far removed from a point where the waste can be sold as fuel, so they have to install a burner especially to get rid of it, if electric drive is used.

Now, I would like, if possible, to hear some arguments that could be put forth to refute those points of view. So far as central station service is concerned, compared with isolated plant service in sawmills, I should unhesitatingly say that, for an installation having over, say, 1000 e.h.p., central station service could complete with an isolated plant very favorably, provided the sawmill was within a reasonable distance of a transmission line. For mills smaller than that I have not seen enough data to be able to tell.

On page 1831, where a comparison is made between operation of logging railways by electricity and by steam, a saving of about $20,000 a year in favor of electricity is shown. I should think that any logging man, no matter how skeptical, would "sit up and take notice," and at least inquire how that could be done.

There is another question in regard to a sawmill: whether steam operation is less efficient from a time standpoint than a motor drive; in other words, whether more time is saved by motor drive than by steam. When a man drives a headsaw with a steam engine and runs into a stiff cut, the steam engine begins to show signs of distress and slows down, and he eases up on his speed; but with a motor the log goes right straight through. I have had that point put up to me two or three times by sawmill men and they claim it is a fact that there is only one thing for the motor to do under such conditions, and that is to blow the fuses. If I understand Mr. Whitney's paper correctly, the development of the electric motor in the last few years has reached such a point that these difficulties are overcome.

A. A. Miller: Last year at the Vancouver convention Mr. E. J. Barry presented a paper on *Logging by Electricity,* and Mr. Whitney contributed very largely to the discussion. It is apparent that Mr. Whitney has been busy during the past year in collecting further data, which have been very systematically assembled in this paper.

I can remember distinctly that only a few years ago loggers and lumbermen in general would not pay any attention to the proposal to use electricity in their operations. The progress made has been very marked, and no up-to-date designer of sawmills would now entirely pass up consideration of electric drive, but would give it very thorough consideration, and in a fair percentage of cases would determine upon electric drive in preference to the old type.

With respect to the question which Mr. Scott asked as to the difficulty encountered in steam drive where the speed of the carriage is diminished in order to allow the saw to speed up again, and where in case of electric drive it is not so regulated but is allowed to go forward at practically constant speed regardless of the load on the motor—this is due to the inherent ability of the motor to carry, temporarily, heavy overloads, and to give such power as is required to take care of the load that may be imposed upon it. That is somewhat allied to the advantage of electric locomotives, in heavy freight work, over steam locomotives, in that for short intervals the capacity of the electric machine is only limited by the amount of power which you can deliver to it. Induction motors, both of the squirrel cage and wound secondary type, for a number of years past have been designed on sufficiently liberal margin to stand tremendous overloads for a period of a minute or so.

F. D. Weber: About seven or eight years ago, I think, the first electrically driven sawmill in Oregon was installed at Dee. Prior to that time there were absolutely no data on this subject. The mill was fitted with all standard squirrel cage motors, with a 150-h. p. squirrel cage motor placed on a double-cut 8-ft. band mill, and after it was installed it was impossible to start the band mill. The only way which they had to start it, and this method was used for years, was by putting a 4 by 4-in. timber in the upper flywheel and having six or eight men throw their weight on it.

A little river runs within about a thousand feet of this mill, and upon this was installed a hydroelectric generating plant to furnish power for the mill.

When this mill was installed they had no consideration at all for sizes of copper, the mill men installing all the wiring. The writer ran tests under operating conditions and found that the copper was about one-half the proper size for satisfactory operation. There was also trouble with the motor connected to the trimmer. This motor was not of sufficient size and necessitated the shutting down of the trimmer occasionally to allow the motor to cool off.

This lumber mill is owned by the Eccles interests, and they were so impressed with the operation of the first mill that when it burned down about two years ago, they replaced it with another electrically operated mill, although it was impossible with their first equipment to operate the band mill double-cut, because when thus operated the motor was unable to carry the load.

There are some questions which I would like to ask Mr. Whitney:

First, have manufacturing companies ever considered furnishing an enclosed type of motor in certain locations in sawmills? After a sawmill has been operated electrically, this blower system that Mr. Whitney spoke about generally fails to keep the mill clean and a great deal of refuse collects, such as sawdust and chips, to which the motors are exposed, consequently a question of fire hazard arises. I have seen motors completely covered with chips and sawdust.

Second, in regard to the motor of the main carriage, I would like to know whether they have had any trouble keeping oil in the bearings of this motor. I should imagine that it would splash out.

Third, I desire to know whether there have ever been any tests made on the load factor of this mill or any other mill.

Fourth, have there been any figures presented concerning the relative cost of installation of electrically driven mills as compared with the first cost of motors? I have heard the argument advanced that the cost of wiring a modern mill is excessive.

Fifth, are there any data concerning the life hazard in logging woods in connection with electrically operated logging engines? It has been said that this hazard was considerable in dense timber where cutting was taking place continually, which might interfere with the transmission lines. Also, the connection between the portable transformer stations and the logging engines, being subjected to the various accidents of the logging woods, might expose the men to live circuits, and produce a serious life hazard.

J. B. Fisken: I want first of all to note that, if I mistake not, the first article in any of the Institute PROCEEDINGS on the subject of the application of electricity to the lumbering industry was a paper by Mr. E. J. Barry, *Electricity in the Lumber Industry*, presented at Los Angeles in April, 1911. Three years later we get a paper from Mr. Whitney, which seems to me as if it might almost be the last; there may be some small improvements, but from what Mr. Whitney tells us the subject has been pretty nearly covered.

There still remain a few things to be done. The question of drying the lumber will involve the generation of steam unless there is a hydraulic plant available; if there is, the drying of the lumber might be done by electricity. The log carriage is not electrically driven in the case we are considering; the operating man might have difficulty in taking care of that. I think it is a question for the manufacturers to solve. The problem of disposition of refuse is a hard one, but in these days of conservation it would seem that some means might be found to take care of this refuse; it must have some commercial value, and unless the cost of saving it is more than the market value, it should be taken care of.

From the standpoint of the operating man, I think the load would be an objectionable one for the reason that it would be very intermittent and severe. Mr. Weber has asked a question regarding the load factor. In the item of costs on page 1828 Mr. Whitney puts in coal at $4.25 a ton. From conditions as I know them I doubt very much if coal could be laid down at the donkey engine for anything like $4.25 a ton. It costs us more than that to lay it down here in Spokane, and to haul it up to any of the logging plants must add very materially to the cost.

Mr. Whitney discusses methods of handling and conserving the refuse. That is a matter, of course, more for the commercial man than for the engineer; at the same time the engineer should work with those who can settle it, and I hope before long to see the sawmills and wood-working factories entirely operated by electricity. I think it is almost invariably the custom now in putting in a large mill to put in electric drive. We have service in this neighborhood that is typical, and from what I have been able to learn the owners would never think of changing back to steam drive.

L. T. Merwin: There is no question in my mind but that the difficulties due to peak loads in sawmill operation can be successfully worked out. Following actual experience of a number of years in electric hoisting under rather severe conditions, I do not think that the question of extreme momentary demand will remain a serious one, even though at the present time it may seem so.

I want to ask a question of Mr. Whitney bearing on the point that Mr. Weber and Mr. Fisken have already brought out, the poor load factor, the highly fluctuating load and the extreme peaks. Has any consideration been given to the handling of these extreme peaks in a manner similar to that in which extreme peaks of mining loads are handled, as, for instance, by some sort of modification of the Illgner-system or by a heavy flywheel set operated by an induction motor? Mr. Whitney mentioned in his paper that of necessity the old manner of running steam-driven mills was from one central drive; I gather that from that they went to the other extreme when first installing electrical drive, and finally have come back to a compromise, with partly group drive. If the flywheel system as applied now to extreme peaks of mining loads can be applied to the sawmill, would that not break down the objections of the central station operating engineer?

Mr. Cheek: As the variable loads that necessarily come upon a motor, it seems to me, would make its protection a very difficult matter, I ask Mr. Whitney what he recommends for the protection of such a motor, whether fuses or other automatic devices. I also ask how the size of the copper is calculated, and whether he has any further information with regard to tests.

I was up in Victoria not long ago and there is a new plant up there that had recently been equipped for making briquets, and they used the refuse, they used the sawdust and also the slabs after going through the hopper; and they claimed that these briquets burn slowly and with much the same characteristics as coal and compared quite favorably with coal.

The matter of the decrease of the fire hazard in logging is a point which I think will act very much in favor of electrical donkeys. This last season was a very dry one and some companies suspended operations during the dry season because of the severe fire hazard of the steam donkey.

A. Norman: The company with which I am connected recently began to supply power to a large sawmill. This mill started in actual operation about three weeks ago, and the mill being entirely new and all of the machinery new, they have not as yet had a full day's operation, and I would not attempt to say just what the load factor will finally be when the mill is in constant operation. However, I could say in a general way that we believe it is going to be about 50 per cent. We feel very much encouraged as to this particular installation, the mill people feel very much encouraged, and I think it offers a fertile field for cooperation between the milling industry and the central station.

In our case, we were so situated that we could furnish this mill not only current for the operation of its motors, but also the steam needed for the dry kiln and for such other purposes as they found it advisable to use steam for. In an installation of some 2100 h. p. in motors I believe we are furnishing them some 225 h.p. for their steam needs. As I say, this installation is so new that we cannot give very full information, but we would be glad to have anyone who is interested in this subject either come to Eugene or Springfield and look into it, or write to us after a brief period, when we expect to get some very definite data, and our company will be very glad to give you any information we have or can get.

W. H. R. Fraser: The largest mill we have connected with our system is probably a good deal smaller than that which Mr. Norman spoke of. The largest mill, I think, has something like 750 to 1000 h. p.; the mill is about nine miles from the nearest substation and is also fed in connection with the same line feeding a town. So this is not a mill line alone, but also a lighting line. We have had no complaint regarding the fluctuation of voltage, so that it cannot have been very bad.

In regard to the utilization of refuse: one mill that I know of has been experimenting with briquets, but whether successfully or not I cannot say. Another mill until recently was trying to produce turpentine from sawdust of certain woods, but that has been a failure.

The question of supplying power to very large mills could scarcely be considered unless very favorably located. One of the largest mills in the world, for instance, has a total capacity of one and three-quarter million a day; driven by individual units; we could never offer them power at a rate that they could consider in preference to installing their own plant; if we delivered power to them we would have to have a 30,000- or 40,000-volt line installed and substations, and by the time we did that the cost of the power to them would be so great that it would be prohibitive.

Another point: I believe that Mr. Whitney mentioned something about coke. I do not think there is a single sawmill in British Columbia using coke today.

F. D. Weber: I remember seeing a note in some trade journal in which it mentioned that there has been a process devised of drying lumber in the open air by the use of quite an appreciable amount of current at low voltage, by simply stacking and separating the layers of lumber by wet carpets. I would like to know if anyone knows anything further on this subject. I understand that is done in Australia and some places in England. If that is the case it seems to me that would solve the question of the dry kiln.

John Harisberger: I may be a little optimistic in regard to companies operating hydroelectric plants selling power to sawmills to their mutual benefit. On our system in the Puget Sound district, we have several mills which have proved quite satisfactory, from both a commercial and an operating standpoint. We also furnish all the power for two coal mines, amounting to 1100 h. p., and several other mines are considering taking our power. I have had some experience in the early days when attempts were first made to operate sawmill machinery by electric motors. The main difficulty was to get sufficient information so as to determine the proper size motors to install. This is entirely different now, as manufactures of electric apparatus and central station people have accumulated a great many data on such applications, so that it is no longer a question of experiment.

E. F. Whitney: I am rather disappointed at the lack of optimism; at the same time I am pleased at Mr. Harisberger's expression that he does look forward favorably to the use of central station power in the sawmills. It can be used, and under certain conditions it can be put in and can operate as cheaply as one can generate and supply his own power, but you must first convince yourselves that it can be done and afterwards convince the mill men. There is always the question of cost of installation and cost of operation.

To begin with the cost of the motors: I have recently completed, in connection with a mill architect, two estimates for entirely different types of mills, one a single-band mill and another a double-band mill, together with the planing mill. Complete estimates were made, first, using steam drive, and second, using electric drive, for each type of mill. The electric mill included the necessary generating station, on the assumption that power would be derived locally from mill refuse. We were surprised to find that for the sawmill alone, electric drive proved lower in first cost—installation cost—than steam, and this without including the planing mill. This latter would have made the balance even greater in favor of electric drive. There is no difference of opinion as regards the very much lower operating and maintenance cost of an electrically driven sawmill.

This of course was an individual case and was figured on its own merits. You will have to let by-gones be by-gones and not consider those mills designed and built along the old lines of steam drive with line shafting and belting and motors placed here and there wherever a drive was needed. The mill must, to get best results, be laid out with electric drive in view, and full advantage taken of its flexibility. We now know what can be accomplished, but the results come only after careful and correct installation and not by chance.

A mill requiring approximately 2300 or 2400 h.p. usually has over 20 separate and distinct engines scattered around its plant; it must have high-pressure steam lines to each one of these engines; the largest would be about 800 h. p. and the smallest about 25 h.p. There need be no further comment than that engines used under such conditions are very uneconomical steam users. An item which is lost track of is the boiler capacity that is required to supply such an installation, and the large initial cost and high upkeep cost of the steam-generating equipment. Electric drive would reduce it at least one-half.

Regarding the ability of the motors to stand up to the work: I recall an instance of a blower, with impellers 80 in. on one side and 70 in. on the other, pressed upon the motor shaft extensions. The motor was rated 100 h. p., 720 rev. per min. The motor did the work satisfactorily, but in the course of an investigation just to see how much power the blowers were taking we found that while the blower specifications called for 96½ h.p., 147 h.p. was the output of that motor, day in and day out, ten hours a day, five hours in the morning and then shut down one hour at noon and then five hours in the afternoon. In this case the motor was in at the top in the planing mill, which is always a well-ventilated structure, it had good cooling air, and the working capability of the motor was increased considerably above what might have been found in a more unfavorable location.

With the present successful mills operating with electric drive, with the proposed largest mill on the coast preparing to use electricity throughout, there can be no question as to the economy of this method or the capability of the electric motor to do the work efficiently and successfully.

The point has been brought up that they must always have steam in the mill. Granting that they must have steam for some uses, there is no necessity for them to have the quantity of steam equipment that will be necessary in all cases except with electric drive.

Upon the question of production: This is the one subject which sawmill men are glad to discuss and consider at any length. They appreciate that their only hope of salvation is to cut down their costs of production. I have known many instances of steam-driven mills where the lag in the steam engine during the cut in the main headsaw is as great as 30 per cent. I have seen the edger lag fully as much. That simply means that they are losing so much productive time. This is unknown with motor drive. Practically all of the motors are squirrel cage type—with a few exceptions, such as the one driving the headsaw; the only reason we use a wound-rotor motor there is because of the limited generating capacity in the average sawmill and to limit the current input at starting. Its characteristics are of course practically the same as the squirrel cage motor after it is up to speed, and any squirrel cage motor would absolutely reach its breakdown point before it had any such regulation as that, unless of a special design. The automatic overload protection and ability to stand up under varying load conditions has already been spoken of. This is an important item when we are driving, for instance, a refuse conveyer. That is probably as severe a drive as any in the mill. With steam drive from the main shaft, if the conveyer should stick, as with a slab jammed under the chain, something must break to clear the trouble. This means lost time, and repairs. With electric drive, we might have the conveyer pretty heavily loaded at times, but of course the relay would be set to care for a predetermined overload with a reasonable time limit, and any more severe condition than that for which it is set should trip the motor out of circuit, and relieve the transmission machinery of the severe strain, saving the breakage that would otherwise occur.

The question of maintenance of voltage was touched upon by Mr. Weber; it is one of the most important points in connection with the operation of electric logging engines. The substation must be 200 to 1000 ft. from the location of the engine itself; in the beginning of the operation it may only be 200 ft., but as the work is extended and the donkey gathers the close timber it will probably be, at the next step, 1000 ft. away. The duty is heavy, often requiring the motor to exert very close to its maximum torque, so we must take the precaution to see that good voltage is the rule at the terminals of the motor. This of course applies to sawmill machinery as well, because we cannot get the maximum productivity unless we maintain our speed and capability to care for heavy loads suddenly applied.

In regard to the question of fire hazard and enclosed motors: This is really the reason that squirrel cage motors are so universally used. In such motors the bearings of course are practically the only source of fire risks. The motor bearings should give very little trouble, and after once being in good condition should require very little attention.

Enclosed motors were never seriously thought of. As to the possibility of dust and chips getting in the windings, the ventilating scheme which has generally been adopted in the manufacture of motors is such that the air comes out through the laminations of the machine and will tend to remove any dust that would clog up the ducts or get into the windings through them. Of course, it would be possible to cover the motor with chips and dust and it would still be operative. The air lines are distributed pretty well around any sawmill at the present time, so that if for the moment any machine shuts down the operator takes his air hose and blows all the dust and chips away. Where it is necessary to use the slip ring type of motor, of course the slip rings should be enclosed. There is a possibility of sparking at starting, and until the motor is up to speed, and it is common practise to enclose them.

On the log carriage some slight trouble has been experienced with oil spashing out of the set works motor bearings. The rate of acceleration of the log carriage at each end of its travel, particularly at the beginning of its return, is very high, but with reasonable precaution, oil-throwing trouble can be remedied. In fact, the first set works motor used was strictly a standard motor, and no trouble was ever experienced with oil splashing out.

In regard to the load factor of a complete mill, we usually assume the demand factor of an electrically driven mill as 70 per cent, in kilowatts, of the connected load in horse power, and the load factor as about 70 per cent. In other words, if you have 1500 h.p. installed, about 750 kw. would be the average load on the mill. I have detailed records of two complete sawmills in the Northwest. One of them has a load factor of 57 per cent. The demand factor is 83 per cent. The average cut per day is 115,000 ft. b.m. The highest peak recorded in any ten minutes was 1150 kw., and the maximum demand for any ten-minute period was 940 kw. The other is a group-drive mill, with 1300 h.p. connected; the load factor is 65 per cent, and the demand factor 88 per cent. The daily cut is 121,000 ft. b.m. (as we would expect with the group drive, a smaller connected load has a larger cutting capacity); the highest peak for any ten-minute period was 1000 kw., the maximum demand for any ten-minute period 850 kw.

The prevailing power factor, I suppose, if we take all of our mills, is roughly 70 per cent; some mills run as low as 50 per cent, some mills run as high as 85 per cent. I have records of a mill which has been in operation for some two years, whose power factor throughout the day's operation never gets below 74 per cent, and there are times when it goes up as high as 85 per cent. That is an extremely high point for a typical induction motor load.

The greatest drawback to the maintenance of a high power factor in sawmills is the small number of large motors that must necessarily be used, which, during a great portion of the time, must certainly run at very light load. Though not less than 200 h.p. is required on the average edger, and a motor somewhere in the neighborhood of 250 or 300 h.p. on the head-saw, the loads averaged per day for these machines will be about 50 and 100 h.p., respectively. The great majority of group drive installations are, as a rule, well loaded and run at good power factors and at good efficiencies. The planing mill equipment has a very fluctuating load; during a portion of its load it runs at a relatively low power factor and low load factor. On the average, a mill of about 2100 h.p., such as Mr. Norman spoke of, under general operating conditions will have a load factor varying from 65 up to 80 per cent. The particular mill of which he spoke has 74 motors with a total of 2053 h.p. connected: the sawmill has 52 motors with 1645 h.p.; the planing mill 18 motors, with 340 h.p. The daily kilowatt-hour consumption had been estimated at from 7500 to 8000 kw-hr. With operations well under way, these figures were confirmed.

As regards the cost of wiring a sawmill installation, that depends largely on the individual. A mill man can put in a wiring job that will equal or excel that in any high-class city office building, or he can put in simply a substantial wiring job that will be satisfactory for his service. There is a difference in cost of, I suppose, 250 per cent. In making up the comparative estimates that I have already spoken of, for steam drive and electric drive, these estimates were based on giving the electrical installation the worst of it in every case that we possibly could, and so we figured on conduit wiring throughout. Even then the wiring cost amounted to about $5500, I think. We had about $9000 which we could have used for this and still come out equal to steam drive.

The fire hazard in the logging industry is something that would have to be given consideration. That, of course, is always brought up whenever the subject is broached to loggers. There is no reason why electrical equipment that is operating a logging camp cannot be as cheaply and as safely handled as it can be in any of our generating stations. The transmission line usually runs along a railroad right-of-way and is just as well protected as any other power company's transmission lines. From it branches are run, depending upon the size of the company's operations; from the substation an armored cable leads out along the ground to the logging engine itself; the cable used is typical submarine cable, which is perfectly safe.

In regard to the question of electric drive for the log carriage: Suppose, for instance, we look at the typical operating cycle of a log carriage given on page 1839. Even with a log of only 1500 ft. b.m. you have a total weight of 38,000 lb., about 19 tons; the requirements of mill operation do not allow the carriage to lag any more than is necessary, and the average speed is about 250 ft. per min. in the cut. That is based, of course, on a single-cutting band mill. The average speed of return is about 650 ft. per min., and we must accelerate that outfit to that speed and maintain it at least for a portion of the travel of the total distance, varying, say, from 40 to 50 ft. as an average. There is not much travel but it is high-speed work, the acceleration is fast, in fact it is all that a person can do to stand on the log carriage and maintain his balance. A log of 1500 ft. b.m. is by no means the heaviest load, it is about an average. If we should get a log of about 5000 ft., or about 40,000 lb., on, it would run the total weight up to something over 35 tons that must be handled at this speed. The common method is by a twin-cylinder, simple steam engine, which operates a drum. The engine, complete with its equipment installed, costs about $3000 to $3500. Any electrical scheme that can compare favorably with it in first cost and in ultimate cost, including operation, will undoubtedly meet with favor from the sawmill people. They would like to do away with the engine, but nothing to compete with it has been shown up to the present time.

The coal and other fuel costs as given on page 1828 applied to logging, not to sawmill operation. In the logging industry they have realized they were burning good merchantable timber as fuel, as the logs cut up and burned under the donkeys must be the very best or they will not split, and on account of the grade of timber they have to use, they have attempted to use oil and coal. Some camps have run comparative outfits to get data on the results accomplished by the use of the various fuels.

In regard to Mr. Fisken's suggestion that additional uses for the refuse be given, and that nothing be said about burners: I attempted to take the point of view of the man who was fully informed about the electrical side of the question but knew very little of a sawmill or its workings. Of course it is necessary for the sawmill operators to dispose of the refuse, because there is too much of it for their own power demands, and this must be got rid of in some way. Usually it is burned in the burners, and they are a source of expense.

I have touched upon the load of the whole mill. I might say that the two cases cited applied to fir districts. In pine districts the load is very much lighter, the connected horse power, we will say, in one case, being 1900 h.p., the load factor only 46 per cent and the demand factor 67 per cent, an average daily cut of 350,000 ft., with a maximum demand for ten minutes of 800 kw. and the highest peak in any ten minutes 950 kw. That is in marked contrast to the greatly increased power demand with smaller cut of the larger fir mill.

Attempts have been made to produce some sort of load equalizer, but only for some individual machines. The fluctuations are not at all regular; they might last for prolonged periods, or might come in quick succession during one or two hours of operation, and might be very infrequent at other times. The demand question must be solved by those desiring to obtain the sawmill load, for its character is to a certain extent fixed.

In the case of the edger there is a machine with no flywheel effect whatever, a simple arbor with five to seven or eight saws, and it is operated by a motor of large capacity. Its highest load comes on instantaneously just as soon as the cant is started through the edger and it lasts until the cant has finished its travel and the cut has been made, seven to ten seconds. Those saws operate at a rim speed of 9000 to 12,000 ft. per min. and at speeds of 1200 to 1800 rev. per min. Any weight that could be added on the shaft of the edger would have to be of such small diameter and great length, to be within the safe limits of even the strongest materials, that it would run the cost up to too large an amount and take up too much space.

These loads are and have been well appreciated by sawmill operators. The operator lays out his plant to care for them. He knows the capacity plant required to care for the load, and in reality the effect of these fluctuations is not to increase the capacity of the equipment which it is necessary for him to have if he is going to generate his own power, and if they do not increase his own capacity why should he spend money to make it a more favorable market for the central station man? That is also the reason why efforts have not been made to obtain a better power factor. Of course it could be obtained, could be done by installing synchronous machinery.

The generating station—isolated or not—must for such a load, have an automatic voltage regulator system, or they cannot expect to accomplish the results which they had anticipated with the electric drive. In operating at say 480 volts at the generator, which is a common voltage, it is exceptional to see the voltage drop below 460. Even with the severest load, such as the starting of the band headsaw, or the edger motor, there is a voltage drop, but it is instantaneous, the voltage going right back to normal again, and under running conditions you very seldom see a fluctuation of the voltage greater than one or two per cent at the outside.

In regard to the use of the refuse for briquets and turpentine, I referred on page 1861 to the experimental use of briquets for paving purposes: " Attempts have been made to use sawdust from Pacific coast mills, which cut mostly fir, spruce, and hemlock, for manufacturing wood alcohol and ethyl alcohol. In practise, however, the manufacturing costs run so high that it has proved unprofitable. The latest projected use is in making sawdust briquets to be used for paving purposes. Such a plant has been completed, although its operations have not extended over a sufficient period to determine the ultimate success." There have been several such attempts made, none of which has proved successful up to the present time, so far as I know.

It would be well to compare the use of the refuse for fuel for a steam generating station, in connection with a large power system, with the development of remotely located water powers. That would open up a field for power installations for the power company which in some cases they could not expect to get otherwise, because of the equipment already installed by the milling company.

I have heard some mention of the electrical drying scheme spoken of by Mr. Weber. I believe that was touched on briefly in *The Timberman* about two months ago. I have heard no comments on its real success.

An interesting feature of the mill spoken of by Mr. Harisberger is that it was the first case of which we have record where the headsaw was direct-connected to a driving motor. They had a double circular headsaw in this particular mill, the lower saw connected directly to the motor and the top saw belted from the lower one; the operation was entirely satisfactory—in fact, it is to be recommended, with proper precautions taken. The log carriage also was driven by a motor. I do not know the particular scheme that was used, but it was not entirely successful from the point of view of sawmill operation, because it did hold back production. Mr. Harisberger said that none of the Everett sawmills is completely operated from central station power. There are two completely electrically operated mills in Everett, however, with a third, the largest on the coast, under construction.

DISCUSSION ON "SPHERE GAP DISCHARGE VOLTAGES AT HIGH FREQUENCIES" (CLARK AND RYAN), DETROIT, MICH., JUNE 24, 1914. (CONTINUED FROM JANUARY PROCEEDINGS, PAGE 124).

(*Subject to final revision for the Transactions.*)

Harris J. Ryan (by letter): Replying to Mr. Fortescue's questions: The high-frequency driving voltage of the arc was multiplied about one hundred times by resonance. The impressed voltage of the arc having an irregular wave form was consumed in the first few turns of the outer helices. Thus in a given case the potential to neutral of the sixth turn from either arc terminal would, on test, be found at low (almost zero) alternating potential. On either side of this turn the potential would be found to rise regularly. By theory, under these circumstances, it is difficult to understand how the high-potential wave form can have departed appreciably from that of the true sine wave. The cyclograph traced a quadrature combination of current and potential waves. The result was a true elipse with no evidence of the presence of harmonics. In regard to the use of isolated spheres made necessary in the method devised to eliminate harmonics in the high frequency high voltage: The case is not one of actual isolation, as assumed by Mr. Fortescue. The arc was supplied with current from two 600-volt direct-current generators connected in series with their neutral grounded. Furthermore, the oscillating circuit would fail utterly to operate unless both sides of the circuit were nicely balanced, developing substantially equal voltages.

We are not asking that our results be accepted as final. The art of generating and handling high-frequency high-voltages is undeveloped as yet. It would not be reasonable to expect final results at this time even with the high-frequency alternator driven at *constant speed* as suggested by one speaker.

In his closing remarks Mr. Peek has accounted for the erratic behavior of the sphere gap voltmeter, cited by Mr. Chubb, when in action above 320,000 volts. He presents his method for eliminating such behavior. Closely related hereto are two experiences encountered in our work.

Regarding the first experience; we have mentioned in our paper that we could not use the condenser voltmeter to measure voltages beyond 50,000. Discharges through the four-inch (aggregate) gap in the two pairs of 7- and 11-inch concentric cylinders, six feet in length, would occur in an erratic fashion at voltages above 53,000. In planning this apparatus we had concluded from the results of Fortescue and others that such discharges should not take place at voltages below 165,000. We expected, therefore, to use the cylinders and instruments with safety for authenticating voltages as high as 125,000 *i.e.* to the limit, of the high-frequency voltage capacity of our equipment. Since the completion of our paper we arranged to subject these concentric cylinders to 60-cycle voltage. In so doing all essentials were made to correspond to those present in the high-frequency work, *i.e.* the neutral of the single-phase 60-cycle source was grounded, while the "neutral" connected outer eleven-inch cylinders were left isolated. They were shunted with the sphere gap set to stop any possible transient over-voltages. Thus arranged, the sphere gap acted in agreement with voltages determined by transformer ratios and voltmeter. The concentric cylinders discharged at voltages all the way from 80 to 100 kilovolts. The lower and higher values occurred correspondingly when the voltage was raised slowly and rapidly. Using one pair of cylinders only, the outer one grounded, the discharge voltages ranged from 40 to 50 kilovolts. The equipment was then dismantled and the seven-inch cylinders were mounted in a cross and separated so as to form a gap between them of three inches; so arranged, 157 kilovolts were required to discharge between them. It seems to us that the free ionization in this case is present in the tarnished and dust coated surfaces of these cylinders, and from there is worked into a line up forming local corona through the two-inch zones of well protected air under the forces of the electric field, thereby starting a disturbance that finishes in a heavy spark, *i.e.*, in a transient discharge, or otherwise, in an actual arcing short circuit. The discharging voltages were lower when the tests were started and gradually rose as the reapplications of high voltage were continued, indicating a sort of cleaning up process.

In the second experience it was found that when using a seven inch sphere gap of two inches or thereabouts, the high-frequency discharge would take place by the shortest path between the spheres at 93 kilovolts. When a lower voltage was applied and a slight disturbance created at one of the surfaces of the opposing spheres by touching it with a piece of hard-rubber a discharge immediately occurred. It would be started by a spark of charging current from the sphere to the hard rubber. Discharges, a foot and more in length would be made to pass from the rearward surface of one sphere to the corresponding rearward surface of the other at 85 kilovolts in the general direction of the lines of force by bringing to the surface of the sphere from the rear a three-quarter inch hard rubber rod.

Mr. Mahood recommends that the Poulsen oscillating arc used for sphere gap voltmeter calibration be replaced by "the best oscillating arcs constructed and specially designed for stability purposes" giving only "*two per cent* variation in amplitude at 133,000 cycles." Such arcs, while steady, are entirely lacking in duty capacity. A maximum of 1500 kilovolt-amperes of reactive power was employed for the high-frequency sphere gap work, while a few hundred volt-amperes suffice for standardizing radio receiving apparatus—accomplished readily enough with such light duty constant arcs. Mr. Mahood confuses the duties of the ammeters in the circuit of the concentric condensers and the potential cyclograph. The former and not the latter read the r.m.s. of the existing potential. The cyclograph gave a continuous vision of the procession of potential oscillations in instantaneous detail. The same speaker makes the suggestion that pure undamped waves were not used in our work because under his own assumption the decrement (for damped waves) was 0.02. The suggestion can not be taken seriously. The cathode ray cyclograph established beyond all reasonable doubt that the oscillating potentials were formed continuously and undamped. These are merely efforts to find near-by evidence to support the theory that the action of the sphere gap voltmeter is independent of the frequency of the applied voltage.

The sphere gap discharge voltages were not altered by the use of the safety resistance rods at 123,000 cycles. They were abandoned at higher frequencies, as stated in the paper, because the resistances that would limit sufficiently the rush of continuous current that followed a discharge across the sphere gaps would consume an undue amount of power, limiting or preventing the generation of voltage in the oscillating circuit.

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MEETING AT NEW YORK, APRIL 9, 1915. See page 83, Sec. I
MEETING AT PITTSBURGH, APRIL 15-16, 1915. See page 83, Sec. I

PROCEEDINGS

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OF

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Vol. XXXIV **April, 1915** No. 4

A. I. E. E. Meeting in New York April 9, 1915

The 307th meeting of the American Institute of Electrical Engineers will be held on the fifth floor of the Engineering Societies Building, 33 West 39th Street, New York, on Friday, April 9, 1915, at 8:15 p.m.

The subject of the meeting will be Radio Telegraphy, and the subject will be briefly introduced by Dr. John B. Whitehead, of Johns Hopkins University. A paper will be presented, entitled *Continuous Waves in Long-Distance Radio Telegraphy*, by L. F. Fuller, and it is expected that another paper covering other phases of the same general subject will also be presented.

At the close of the technical session a smoker will be held and light refreshments served in the adjoining room on the fifth floor.

Members of the Institute of Radio Engineers are invited to attend the meeting and to take part in the discussion.

A. I. E. E. Meeting at Pittsburgh

The 308th meeting of the American Institute of Electrical Engineers will be held in Pittsburgh, Pa., on Thursday and Friday, April 15 and 16, 1915. The meeting will be under the auspices of the Pittsburgh Section and the Industrial Power Committee. The Convention headquarters of the Institute will be at the Fort Pitt Hotel, where the technical sessions will also be held. The program will be as follows:

Thursday, April 15

9:30 A.M.

Meeting to be opened by Mr. J. W. Welsh, Chairman, Pittsburgh Section.

Introductory address by Mr. David B. Rushmore, Chairman, Industrial Power Committee.

Address by President P. M. Lincoln.

1. *Industrial Control in the Foundry*, by R. H. McLain.

2:00 P.M.

2. *Mills Controllers*, by H. F. Stratton.
3. *Steel Mill Controllers from the Operator's Standpoint*, by James S. Riggs.

Friday, April 16

9:30 A.M.

4. *Control of Direct-Current Hoists in Iron and Steel Mills*, by E. G. Stoltz and W. O. Lum.
5. *Direct-Current Control for Hoisting Equipment in Industrial Plants*, by W. T. Snyder.

2:00 P.M.

6. *Control of Alternating-Current Motors in Iron and Steel Mills*, by Arthur Simon.
7. *The Alternating-Current Hoist*, by Raymond E. Brown.

Papers Nos. 1, 2 and 7 are published in this issue of the PROCEEDINGS. Advance copies of the other papers will be distributed at the meeting.

A. I. E. E. Annual Convention

The 32nd Annual Convention of the American Institute of Electrical Engineers will be held at Deer Park, Maryland, June 29, 30, July 1, 2, 1915. The Convention headquarters will be at the Deer Park Hotel, where the technical sessions will be held.

The following convention committee has been appointed by President Lincoln to take charge of the convention arrangements, with the exception of the technical program:

Messrs. John H. Finney, Chairman,
513 National Metropolitan Bank Bldg., Washington, D. C.
H. H. Barnes, Jr., New York.
V. W. Bergenthal, St. Louis, Mo.
A. W. Berresford, Milwaukee, Wis.
J. H. Davis, Baltimore, Md.
G. Faccioli, Pittsfield, Mass.
J. J. Kline, Fort Wayne, Ind.
A. S. McAllister, New York.
J. C. McQuiston, East Pittsburgh, Pa.
N. J. Neall, Boston, Mass.
Homer E. Niesz, Chicago, Ill.
Farley Osgood, Newark, N. J.
Lewis T. Robinson, Schenectady, N.Y.
A. M. Schoen, Atlanta, Ga.
J. Franklin Stevens, Philadelphia, Pa.
Charles W. Stone, Schenectady, N.Y.
Charles E. Waddell, Biltmore, N. C.

The following tentative program has been arranged:

Tuesday, June 29

10:00 A.M.—12:30 P.M.

President's Address.

1. *The Electric Strength of Air*—VI, by J. B. Whitehead.
2. *The Reluctance of Some Irregular Magnetic Fields*, by John F. H. Douglas.

12:30—2:30 P.M.

Sections Committee Luncheon.

2:30—5:00 P.M.

3. *The Measurements of Dielectric Losses with the Cathode Ray Tube*, by John P. Minton.
4. *Irregular Wave Forms*; *The Significance of Form Factor, Distortion Factor and Other Factors*, by Frederick Bedell.

9:00 P.M.

Reception.

Wednesday, June 30

10:00 A.M.—12:30 P.M.

5. *Classification of Alternating-Current Motors*, by Val A. Fynn.
6. *Alternating-Current Commutator Motor Classification and Nomenclature*, by Frederick Creedy.
7. *Short Circuits on Alternators*, by Comfort A. Adams.
8. *Electricity in Grain Elevators*, by H. E. Stafford.
9. *Fields of Motor Application* (*Topical Discussion*), by D. B. Rushmore.

12:30—2:30 P.M.

Sections Committee Luncheon.

8:15 P.M.

Joint meeting with Illuminating Engineering Society.

10. *The Effective Illumination of Streets*, by Preston S. Millar.
11. *Systems of Street Illumination*, by Charles P. Steinmetz.

Thursday, July 1

10:00 A.M.—12:30 P.M.

12. *Construction and Maintenance Costs of Overhead Contact Systems*, by E. J. Amberg and Ferdinand Zogbaum.
13. *The Contact System of the Butte, Anaconda and Pacific Railway*, by J. B. Cox.
14. *Third Rail and Trolley System of the West Jersey and Seashore Railroad*, by J. V. B. Duer.
15. *Top Contact Unprotected Contact Rail for 600-Volt Traction System*, by Charles H. Jones.
16. *Under-Running Third Rail Conductors*, by Edwin B. Katte.

12:30—2:30 P.M.

Board of Directors Luncheon.

8:15 P.M.

Section Delegates Meeting.

Friday, July 2

10:00 A.M.—12:30 P.M.

17. *Phase Angle of Current Transformers*, by Chester L. Dawes.
18. *Instrument Transformers*, by Charles L. Fortescue.
19. *The Induction Watt-Hour Meter*, by V. L. Hollister.

12:30—2:30 P.M.

Sections Committee Luncheon.

2:30—5:00 P.M.

20. *Economic Operation of Electric Ovens*, by Percy W. Gumaer.
21. *Class Rates for Electric Light and Power Systems*, by Frank G. Baum.

Deer Park, Maryland, is on the main line of the Baltimore and Ohio Railroad and is the largest summer resort in the Allegheny Mountains, being 2,800 feet above sea level. It is 11 hours from Cincinnati or New York, 9 hours from Philadelphia, 7 hours from Pittsburgh, 13 hours from Columbus, 21 hours from Chicago, and 12 hours from Cleveland, and it has through Pullman car service from all of these cities.

The hotel is situated about 300 yards from the railway station and is divided into three parts, the main building and eastern and western annexes. It is equipped with every modern appliance for the convenience of guests, and has large airy rooms, spacious verandas, and covered passageways between the main building and annexes. Pool rooms, bowling alleys, golf links, tennis courts, baseball grounds, etc., will be available to members without charge. An orchestra will be provided by the hotel to furnish music for dancing.

Its location on the mountain top insures a delightful temperature and the hotel is supplied with spring water from the famous Boiling Springs, which have a national reputation. The convention hall has a seating capacity for 300 people.

The hotel rates per day are $3.00, $4.00 and $5.00.

Panama-Pacific Convention, San Francisco, September 16-18, 1915

The Panama-Pacific Convention Committee is actively at work making plans and arrangements for this convention, which is to be held in San Francisco, September 16-18, 1915, during the week immediately preceding the International Engineering Congress.

The personnel of the Convention Committee appointed by President Lincoln is as follows: Messrs. W. W. Briggs, Chairman, A. H. Babcock, A. M. Hunt, A. G. Jones, H. A. Lardner, J. T. Whittlesey, and C. J. Wilson, all of San Francisco; Prof. C. L. Cory, University of California; Prof. Harris J. Ryan, Leland Stanford, Jr. University; Mr. L. T. Robinson, Chairman, Institute Meetings and Papers Committee; Messrs. H. H. Barnes, Jr. and George F. Sever, of New York.

The first meeting of the Convention Committee was held at the Engineers' Club, San Francisco, February 19, at which there was a general discussion of plans for the convention, and the following appointments as chairmen of the sub-committees indicated were made: Mr. H. A. Lardner, Chairman, Meetings and Halls Committee; Mr. C. J. Wilson, Chairman, Entertainment Committee; Mr. A. H. Babcock, Chairman, Local Papers Committee.

The San Francisco committee has already made reservations of ample accommodations in the Auditorium Building for holding the technical sessions and other meetings of the convention. The official headquarters of the Institute will be at the Hotel St. Francis. Information regarding transportation and hotel accommodations was mailed to the membership last week in a circular issued by the Committee on Transportation of the International Engineering Congress.

It has been decided to limit the technical sessions to the mornings and afternoons of Thursday and Friday, September 16 and 17, thus leaving the remainder of the time free for inspection trips or other plans.

The Meetings and Papers Committee is active in formulating its plans for the technical sessions. Further information willl be published in the PROCEEDINGS from month to month.

Honorary Vice-President for Pacific Coast

At the March meeting of the Board of Directors, Professor Harris J. Ryan was appointed Honorary Vice-President of the Institute on the Pacific Coast, during the Panama-Pacific Exposition, by the adoption of the following resolution:

> " *Resolved* that Professor Harris J. Ryan, of Leland Stanford Jr. University, California, be and he hereby is appointed Honorary Vice-President of the American Institute of Electrical Engineers, to act as a special honorary representative and officer of the Institute, on the Pacific Coast, during the Panama-Pacific Exposition."

It was the belief of the Board that the importance of the occasion on the Pacific Coast justified the creation of this special honorary office, and there was a general desire to honor Professor Ryan as an eminent member and former Vice-President of the Institute by his appointment to this office.

Report of Committee of Tellers on Nomination Ballots

To the Board of Directors, American Institute of Electrical Engineers:

Gentlemen: This committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1915-1916. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		1426
Rejected on account of bearing no identifying name on outer envelope	34	
Rejected on account of having reached the Secretary's office after February 28	71	105
Leaving as valid ballots		1321

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

John J. Carty	1209
Scattering and blank	112
Total	1321

(The scattering vote was divided among 17 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR VICE-PRESIDENTS

Comfort A. Adams, Cambridge, Mass	1021
Harris J. Ryan, Stanford University, Cal	865
J. Franklin Stevens, Philadelphia, Pa	793
William McClellan, New York	786
*William B. Jackson, Chicago, Ill	73
Scattering and blank	425
Total	3963

(The scattering vote was divided among 51 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR MANAGERS

John B. Taylor, Schenectady, N. Y	603
Harold Pender, Philadelphia, Pa	603
C. E. Skinner, Pittsburgh, Pa	586
Henry Floy, New York	439
N. J. Neall, Boston, Mass	399
Philander Betts, Newark, N. J	397
F. B. Jewett, New York	392
H. A. Hornor, Philadelphia, Pa	296
Hugh Hazelton, New York	254
N. A. Carle, Newark, N. J	242
Harris J. Ryan, Stanford University, Cal	188
Stefaan Piek, Buffalo, N. Y	140
*E. J. Berg, Schenectady, N. Y	108
Scattering and blank	637
Total	5284

(The scattering vote was divided among 59 candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

*Candidates withdrew their names prior to printing of nomination ballots, and their withdrawal was therefore indicated on these ballots.

FOR TREASURER

George A. Hamilton	1131
Scattering and blank	190
Total	1321

Respectfully submitted,
FREDERICK BORCH, *chairman.*
CHARLES A. ROHR,
WALTER S. HOYT,
H. B. HAMMOND,
RAYMOND C. DARROW,
Committee of Tellers.

Directors' Meeting, New York, March 12, 1915

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, Friday, March 12, 1915, at 3:30 p.m.

Present· President P. M. Lincoln, Pittsburgh, Pa.; Past-Presidents Ralph D. Mershon and C. O. Mailloux, New York; Vice-Presidents C. E. Scribner, New York, Farley Osgood, Newark, N. J.; Managers Comfort A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William B. Jackson, and Peter Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y., William McClellan, Bancroft Gherardi, and A. S. McAllister, New York, John H. Finney, Washington, D. C.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,631.49 was ratified.

On behalf of the Executive Committee, which at the last directors' meeting had been empowered to decide upon the location for the Annual Convention of the Institute for 1915, President Lincoln reported that the committee recommended that the convention be held at Deer Park, Maryland, June 29–July 2. The recommendation of the Executive Committee was approved by the Board.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred seven Associates to the grade of Member, elected one applicant as Member and 82 as Associates, and ordered the enrolment of 44 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

The report of the Tellers Committee giving the results of its canvass of the nomination ballots received for the offices to be filled at the next annual election was presented. The Board selected by ballot, as required by the Constitution, its list of Directors' Nominees for the offices falling vacant, with the following result:

For President, John J. Carty, New York; for Vice-Presidents, Comfort A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., and William McClellan, New York; for Managers, John B. Taylor, Schenectady, N. Y., C. E. Skinner, Pittsburgh, Pa., F. B. Jewett, New York, Harold Pender, Philadelphia, Pa.; for Treasurer, George A. Hamilton, Elizabeth, N. J.

In accordance with the Constitution, these Directors' Nominees will be indicated on the election ballot which will be mailed to the entire membership not later than April 1, together with the names of all members who received not less than three per cent of the entire number of nomination votes cast.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

Past Institute Meetings

New York.—The 305th meeting of the Institute, a joint meeting with the New York Section of the American Electrochemical Society, was held Friday, March 12, 1915, in the auditorium of the Engineering Societies Building, beginning at 8:25 p. m. President Paul M. Lincoln presided.

Mr. Leland L. Summers first presented his paper, *Fixation of Atmospheric Nitrogen*, and then President Lincoln introduced Mr. Frank B. Washburn of the American Electrochemical Society, who presented his paper, entitled "The Cyanamide Process in the Production of Nitrogen." The discussion of the two papers was opened by Professor Joseph W. Richards, Secretary of the American Electrochemical Society, who was followed by Messrs. J. L. R. Hayden, David B. Rushmore, Charles A. Doremus, F. V. Henshaw, Frank B. Washburn, and Leland L. Summers.

At the close of the technical session,

a smoker was held in the Institute rooms on the tenth floor.

Past Section Meetings

Baltimore.—January 22, 1915, Physical Laboratory of Johns Hopkins University. Subject: Telegraphy. Paper: "Modern Telegraph Methods," by Louis M. Potts, illustrated by lantern slides. Attendance 25.

February 26, 1915, Physical Laboratory of Johns Hopkins University. Subject: High-Tension Transmission. Paper: "Four Years' Operating Experience on a High-Tension Transmission Line," by A. Bang, illustrated by lantern slides. Attendance 32.

Boston.—February 15, 1915, Boston City Club Building. Sixth annual dinner of the Engineers of Boston, under auspices of Civil Engineers, Mechanical Engineers and Electrical Engineers. Short addresses by Gov. David I. Walsh of Massachusetts, and Messrs. Charles W. Baker, Charles H. Eglee, James W. Rollins, and Harrison P. Eddy. Capt. Robert W. Bartlett gave some personal narratives of northern expeditions. Attendance 280.

February 26, 1915, Wentworth Institute. Addresses by Professors A. L. Williston and Thomas N. Carver, and Messrs. Walter C. Fish, Henry S. Dennison and William B. Hunter, on Industrial Education. Joint meeting of Civil, Mechanical and Electrical Engineers. Attendance 215.

Cleveland.—February 15, 1915, Electrical League Rooms, Hollenden Hotel. Papers: (1) "Searchlights," by R. B. Chillas, (2) "Lighthouse Illumination," by Raymond Haskell. Attendance 36.

Detroit-Ann Arbor.—February 12, 1915, Detroit Engineering Society Club Rooms. Paper: "Development of Niagara Falls Power Company," by R. W. Ten Brook, illustrated by lantern slides. Attendance 60.

February 26, 1915, Detroit Engineering Society Club Rooms. Subject: Illumination. Paper: "Illuminating Engineering and the Problem of Waste," by H. H. Magdsick, illustrated with lantern slides. Attendance 60.

Fort Wayne.—February 18, 1915, Commercial Club. Address by Mr. E. J. Brobst on "Automatic Starting and Lighting Systems." Attendance 18.

Ithaca.—January 22, 1915, Franklin Hall, Cornell University. Lecture by Mr. Elmer A. Sperry on "The Electrically Driven Gyroscope in Service." The lecture was illustrated by the operation of an electrically driven gyroscope, also lantern slides showing applications of the gyroscope. Attendance 325.

February 12, 1915, Franklin Hall, Cornell University. Subject: Electric Railways. Paper: "Some Recent Developments in Electric Railway Practise and Equipment," by Paul H. Smith, illustrated with lantern slides. Attendance 80.

Los Angeles.—February 16, 1915, Chamber of Commerce. Subject: Distribution. Paper: "The Essentials of a Down-to-Date Distributing System," by R. E. Cunningham. Attendance 40.

Lynn.—February 17, 1915, General Electric Works, West Lynn. Illustrated lecture by J. Lester Woodbridge on "The Characteristics and Uses of Storage Batteries." Attendance 322.

March 10, 1915, General Electric Works. Illustrated lecture by J. G. Patterson on "Up-to-Date Telephone Problems." Attendance 237.

Milwaukee.—January 29, 1915, Plankinton House. Meeting under auspices of Milwaukee Section of American Chemical Society. Illustrated address by Dr. J. H. Mathews on "Some Recent Advances in the Processes of Color Photography." Attendance 80.

February 10, 1915, Intake Tunnel, Lake Park. Inspection trip through Intake Tunnel at Lake Park, under auspices of Engineers Society of Milwaukee. Attendance 150.

Philadelphia.—February 8, 1915, Engineers' Club. Subject: Illumination. Papers: (1) "Progress in Illumination during the Past Year," by George A. Hoadley; (2) "The Incandescent Lamp, Its Recent Development and Application," by George H. Stickney. Joint meeting with Philadelphia Section of Illuminating Engineering Society. Attendance 130.

February 11, 1915, Franklin Institute. Paper: "Recent Researches in Electricity at the Bureau of Standards", by Dr. E. B. Rosa. Joint meeting with Franklin Institute. Attendance 200.

March 8, 1915, Engineers' Club. Paper: " The Fundamental Equations of Wave Motion on Transmission Lines," by W. S. Franklin. Attendance 80.

Pittsburgh.—February 9, 1915, Oliver Building. Subject: Electricity in Marine Work. Paper: "The Electrical Equipment of a Battleship," by H. A. Hornor, illustrated with lantern slides. Attendance 140.

Pittsfield.—February 25, 1915, General Electric Restaurant. Sixth annual dinner of Pittsfield Section. Attendance 110.

Portland.—March 2, 1915. Subject: Accounting. Paper: " Cost Accounting from the Engineer's Standpoint," by J. C. Martin. Joint meeting with N. E. L. A. Attendance 70.

Rochester.—February 26, 1915. Paper: " Long-Distance Transmission of Measurements," by J. W. Ward. Attendance 38.

San Francisco.—February 26, 1915, Engineers' Club. Paper: " Electric Utility Financing," by George K. Weeks. Attendance 65.

Schenectady.—February 24, 1915, Edison Club Hall. Moving pictures of different departments of General Electric works, also of Panama Canal. Pictures explained by Mr. C. F. Bateholts, who also gave a talk on uses to which moving pictures are put for advertising and amusement. Attendance 400.

March 2, 1915, Edison Club Hall. Subject: Motor Control. Paper: " The Principles and Systems of Control for Electric Motors," by C. D. Knight. Attendance 138.

March 16, 1915, Edison Club Hall. Paper: " The Cotton Industry," by Sidney B. Paine. Attendance 138.

Seattle.—February 16, 1915, Central Building. Papers: (1) "Crude Oil Diesel Engine Plant," by E. A. Ransom; (2) "Gas Engine Plant," by L.P. Tolman; (3) " Steam Plant," by H. W. Beecher; (4) " Hydroelectric Plant", by G. H. Moore. Attendance 32.

Spokane.—January 15, 1915, Chamber of Commerce Building. Papers: (1) " Some Features of Parallel Operation," by L. J. Corbett; (2) " Secondary Grounds and Ground Testing," by G. H. Hoppin. Address by Mr. Barry Dibble on " Use of Electricity by the Government." Attendance 21.

February 19, 1915. Addresses: " The Function of Capacity and Inductance in Tuning in Wireless Telegraphy," by F. A. Ruppert, and " Instruments which Comprise a Wireless Station, and Their Functions,'" by E. V. Olson. Demonstration of wireless apparatus. Paper: " The Best Control of Public Utilities," by F. G. Baum. Attendance 82.

St. Louis.—February 10, 1915. Engineers Club. Paper: " Special Industrial Applications of Electricity," by J. A. Osborne. Attendance 50.

March 12, 1915, City Club. Illustrated travelogue by Mr. S. N. Clarkson on his recent trip from St. Louis to Australia and return. Attendance 150.

Toledo.—March 3, 1915, Toledo Commerce Club. Address by Mr. E. H. Martindale on " Use and Misuse of Carbon Brushes." Attendance 20.

Urbana.—February 12, 1915, Electrical Laboratory. Lecture by Professor Ellery B. Paine on " A New Type of Electrical Condenser," followed by experimental demonstrations. Attendance 72.

Washington.—February 9, 1915, Cosmos Club Hall. Address by Mr. Hugh L. Cooper on the Keokuk and other hydroelectric works upon which he has been engaged. Attendance 60.

Past Branch Meetings

University of Alabama.—February 22, 1915, Comer Hall. Paper: "Load Factors," by T. D. Johnson. Attendance 10.

March 8. 1915, Comer Hall. Address by Mr. E. C. Brantley on "Outdoor Substations." Attendance 17.

University of Arkansas.—February 23, 1915, Engineering Hall. Papers: (1) "Niagara Power Development;" (2) "Electrical Operation of the Butte, Anaconda and Pacific Railway;" (3) "Sparks." Attendance 14.

March 2, 1915. Papers: (1) "Automobile Engine Trouble;" (2) "Magnetic Properties of Electric Iron;" (3) "Sparks." Attendance 15.

March 9, 1915. Paper: "Electric Welding," illustrated with lantern slides.

Armour Institute.—February 18,1915, Science Hall. Illustrated lecture on "The Manufacture of Rubber-Covered Wires and Cables," by Henry A. Morss. Attendance 129.

University of Cincinnati.—February 9, 1915. Address by Mr. Shepard on "Remote Control." Attendance 77.

March 5, 1915. Illustrated address by Mr. Yocum on "High-Voltage D-C. Railways." Attendance 17.

Clemson College.—February 9, 1915, Steam Lecture Room. Papers: (1) "Steel Towers for Electrical Transmission;" (2) "The Growth of Electrical Systems in the South;" (3) "Review of the Electrical Periodicals for February." Attendance 34.

University of Colorado.—February 11, 1915. Address by Mr. L. S. Ickis on "The Value of a Technical Education to the Practising Engineer." Attendance 21.

February 25, 1915. Address by Mr. John Salberg on "The Effects of Electricity on Industrial Revolution." Attendance 37.

Georgia School of Technology.—February 5, 1915, Electric Building. Paper: "Modern Developments in Distributing Transformers, and Capitalization of Transformer Losses," by Thomas Fuller. Attendance 47.

February 12, 1915, Chemistry Building. Paper: "Application of Individual Motor Drive to Textile Machinery," by C. Emerson. Attendance 46.

February 19, 1915, Electric Building. Lecture by Mr. R. L. Hughes on "Otis Elevators." Attendance 37.

Highland Park College.—February 3, 1915, Main Building. Address by Mr. W. E. Byerts. Attendance 47.

February 17, 1915. Papers: (1) "Illumination Measurements;" (2) "Factory Lighting;" (3) "Lighting Schedules;" (4) "The Design of Illumination for Large Rooms." Attendance 68.

University of Kansas.—February 8, 1915, Engineering Building. Paper: "Water Purification," illustrated by lantern slides. Attendance 30.

University of Kentucky.—February 18, 1915, Mechanical Hall. Illustrated lecture by Mr. W. M. Hannah on "Modern Practise in Electrical Power Plant Equipment." Attendance 35.

March 7, 1915. Paper: "Uses and Applications of Fractional Horse Power Motors." Attendance 52.

Lafayette College.—February 11, 1915, Pardee Hall. Papers: (1) "Train Lighting Systems;" (2) "Electrification of Chicago, Milwaukee and St. Paul Railroad." Attendance 21.

March 4, 1915. Papers: (1) "The Booster Rotary;" (2) "Electric Furnaces, Types and Operators;" (3) "Public Service Commissions in America;" (4) "Determination of Wave Length in Radiotelegraphy." Attendance 21.

Lehigh University.—February 12, 1915, Physics Lecture Room. Papers: (1) "Senior Electrical Engineers' Trip to New York," by C. M. Seiger; (2) "Side Lights on Our Work with the Lehigh Navigation Electric Company", by E. F. Weaver and A. G. Birdsall. Attendance 41.

University of Missouri.—February 15, 1915, Engineering Building. Address by Mr. C. R. Born on "Telephone Engineering." Attendance 23.

March 3, 1915. Paper: "Industrial Applications of Electric Motors," by M. P. Weinbach. Attendance 20.

Montana State College.—February 26, 1915, Physics Lecture Room. Illustrated lecture by Mr. C. D. Kunkel on "Electricity in Mining." Attendance 34.

University of Nebraska.—February 3, 1915. Address by Prof. L. B. Tuckerman, Jr., on "The Latest Developments in Radio Telegraphy and Telephony."

North Carolina College of Agricultural and Mechanical Arts.—February 16, 1915. Illustrated lecture by Mr. W. M. Gallant on "The Watt-Hour Meter, and Switchboard Instruments." Attendance 32.

March 2, 1915. Paper: "Electrification of the Cascade Tunnel of the Great Northern Railway," illustrated by lantern slides. Attendance 25.

March 9, 1915. Demonstration of the aluminum-carbon electrolytic rectifier. Address on "High-Tension Portable Substations." Attendance 22.

Ohio Northern University.—February 17, 1915, Hill Memorial. Papers: (1) "Electric Automobile Starters," by C. R. Alden; (2) "Epstein Test," by M. Kitriff; (3) "Engineering Ethics," by Prof. McEachron. Attendance 33.

Ohio State University.—February 19, 1915, Robinson Laboratory. Papers: (1) "Sphere Gap," by J. K. Swigart; (2) "Power Plant Accidents," by C. D. Powell. Attendance 30.

March 5, 1915. Papers: (1) "The Present Status of Prime Movers;" (2) "Edison; A Brief Review of His Early Life." Attendance 36.

University of Oklahoma.—February 17, 1915. Papers: (1) "Public Utilities," by R.W. Stinson; (2) "Current Topics," by Charles L. Wolfe; (3) "George W. Goethals," by W. Hott. Attendance 14.

Oklahoma Agricultural and Mechanical College.—February 10, 1915. Papers: (1) "Reinforced Concrete Posts for Transmission Lines," by H. K. Weber; (2) "Electrolytic Rheostats," by H. C. Woodson. Attendance 37.

Oregon Agricultural College.—February 16, 1915. Paper: "Underwriting and the Electrical Contractor," by F. D. Weber. Attendance 13.

March 2, 1915. Paper: "The Possibilities of Hydroelectric Development in Oregon," by L. F. Harza. Attendance 45.

Pennsylvania State College.—January 20, 1915, Engineering Club Room. Paper: "The Work of the College Graduate," by Dean Kinsloe. Attendance 63.

February 18, 1915. Papers: (1) "The Development of the Commercial Wireless Telegraph," by W. M. Stemple; (2) "Advantages of Membership in the A. I. E. E.," by D. E. Winslow. Attendance 46.

University of Pittsburgh.—February 8, 1915, Thaw Hall. Address by President P. M. Lincoln on "The Young Engineer." Attendance 51.

Rensselaer Polytechnic Institute.—February 16, 1915, Sage Laboratory. Illustrated lecture by Messrs. R. V. Hoopes and C. D. Zimmerman on "Oil Switches." Attendance 45.

Rhode Island State College.—February 17, 1915, Lippitt Hall. Address by Mr. Leon Harris on "Industrial Power and Its Different Phases." Attendance 23.

March 10, 1915. Address by Mr. C. E. Seifert on "The Commutating Pole Motor and Its Different Phases." Prof. Dickenson gave a demonstration in connection with the Address. Attendance 25.

Rose Polytechnic Institute.—March 2, 1915. Papers: (1) "Use of Thermit in War," by R. M. Smith; (2) "Deterioration of Concrete due to Electrolysis." by H. A. Smith. Attendance 34.

Stanford University.—February 4, 1915, Engineering Building. Paper: "Watt-Hour Meters." Attendance 20.

Syracuse University.—February 11, 1915. Address by Mr. J. A. Coy on "The Power Plant of the Fort Worth Electric Company." Attendance 18.

February 18, 1915. Paper: "Locomotives for the Panama Canal." Attendance 14.

February 25, 1915. Paper: "Social Economy as Practised at the Western Electrical Instrument Company," by George W. Parsons. Attendance 17.

March 4, 1915. Paper: "Telephone Engineering", by C. S. Abren. Attendance 17.

Agricultural and Mechanical College of Texas.—February 13, 1915, Electrical Engineering Building. Paper: "The Present Standing of the Motor as a Means of Machine Drive," by G. H. Froebel. Attendance 50.

University of Texas.—January 29, 1915. Illustrated lecture by Mr. W. M. Clayton on "Some Features in the Construction of the Modern Transformer." Attendance 22.

February 19, 1915. Illustrated lecture by Dr. S. L. Brown on "Hydroelectric Developments on the Pacific Coast." Attendance 23.

Virginia Polytechnic Institute.—February 24, 1915. Election of officers as follows—chairman, M. F. Peake; secretary, J. R. Murphy. Attendance 52.

University of Virginia.—March 2, 1915, Mechanical Laboratory. Papers: (1) "Towing Locomotives on Panama Canal;" (2) "100,000-Volt Portable Transformers;" (3) "Electrical Equipment of Battleships." Attendance 16.

University of Washington.—February 9, 1915, Good Roads Building. Address by Mr. R. F. Robinson on "Some Operating Features of Practical Telephony." Short talk on "Telephone Trouble" by Mr. H. W. McRobbie. Attendance 25.

March 2, 1915. Address by Mr. R. E. Thompson on "Radiotelegraphy." Attendance 42.

West Virginia University.—March 5, 1915. Recent Institute papers were abstracted and discussed. Attendance 40.

Worcester Polytechnic Institute.—February 19, 1915. Illustrated address by Mr. G. H. Throop on "Valuation of Public Utilities." Attendance 150.

Yale University.—February 16, 1915, Electrical Laboratory. Paper: "New Lighting Methods," by C. E. Clewell. Attendance 135.

Personal

MR. WALTER ROBBINS, for many years assistant general manager of the Wagner Electric Manufacturing Company of St. Louis, has been elected a vice-president of the company.

DR. CARL HERING of Philadelphia, Past-President and Fellow of the Institute, was recently elected a Fellow of the American Association for the Advancement of Science, of which he has been a member for many years.

MR. J. G. DEREMER has assumed the management of the general engineering department of the American District Steam Company, North Tonawanda, N. Y. Mr. DeRemer was formerly chief mechanical and electrical engineer of the United Light and Power Company, San Francisco, Cal.

MESSRS. L. B. MARKS and J. E. WOODWELL, consulting engineers, 103 Park Avenue, New York, announce that they will dissolve partnership on May 1, 1915. Mr. Woodwell will locate his offices at 8 West 40th Street, where he will continue the general practise of consulting engineering, and Mr. Marks will retain his offices at 103 Park Avenue and will specialize, as heretofore, in illuminating engineering.

MR. H. A. STEEN has been appointed electrical engineer in charge of the New Jersey Zinc Company's electrical equipment in Franklin and Ogdensburg, New Jersey, including power plant, motor and light installations and power transmission. Mr. Steen has been connected with the Westinghouse Electric and Manufacturing Company, the Allis-Chalmers Manufacturing Company and the Cutler-Hammer Company in the capacity of designing engineer for the past 14 years.

Transferred to the Grade of Member March 12, 1915

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on March 12, 1915.

Dudley, Wray, Local Engineer, General Electric Co., Pittsburgh, Pa.

Gupta, Birendra C., Professor of Electrical Engineering, C. E. College, Sidpur, India.

Hehre, Frederick W., Instructor of Electrical Engineering, Columbia University, New York, N. Y.

MacGahan, Paul, Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

Moreland, Edward L., Manager of Boston Office, D. C. & W. B. Jackson, Boston, Mass.

Parkhurst, Austin Flint, Division Supt., Tropical Radio Telegraph Co., New Orleans, La.

Shrewsbury, Lewis Alfred, Supt., Electrical Dept., Cia Minera Las Dos Estrellas, Mexico City, Mexico.

Member Elected March 12, 1915

Langley, Gordon R., Switchboard Engineer, Canadian General Electric Co.; res.. 301 Margaret Ave.. Peterboro, Ont.

Associates Elected March 12, 1915

Aime, Frank L., Construction Foreman, Electric Dept., Pittsburgh Railways Co.; res., 6205 Alder St., Pittsburgh, Pa.

Arnold, Forest G., Engineer, Commonwealth Edison Co., 72 West Adams St., Chicago, Ill.

Axell, Charles G., Chief Draftsman, Commonwealth Edison Co., 72 W. Adams St. Chicago, Ill.

Baker, John S., Assistant Engineer, McMeen and Miller, 1454 Monadnock Block, Chicago, Ill.

***Baugher, Edward J.**, Engineer, West Virginia Traction & Electric Co., Wheeling, W. Va.

Bennett, John L., Construction Dept., Ft. Wayne Electric Works; res., 1203 W. Jefferson St., Ft. Wayne, Ind.

Berg, Lars, Electrical Engineer, Bergen Municipal Electric Light & Power Co., Elektricitetsverket, Bergen, Norway.

Bigelow, Charles H., Chief Mechanical Engineer, Millville Mfg. Co., Millville, N. J.

Blake, Alfred D., Associate Editor, *Power*, 10th Ave. & 36th St., New York; res., 4 Ohio Pl., West New Brighton, S. I., N. Y.

***Boggs, Clarence E.**, Superintendent, Klees Electric Co., Summerville, Ore.

Brown, John Wilson, General Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1102 South Ave , Wilkinsburg, Pa.

Brown, Raymond S., Asst. Electrical Engineer, Northern California Power Co.; res., 702 Butte St., Redding, Cal.

***Brumhall, John H.**, Iowa Railway & Light Co., Boone, Iowa.

***Bryan, Henry C.**, Production Dept., Ft. Wayne Electric Works of G. E. Co.; res., 1326 W. Jefferson St., Ft. Wayne, Ind

***Burleigh, Arthur C.**, Chief Electrician, Riter-Couley Mfg. Co., Leetsdale, Pa.

***Cadwallader, James Albert**, Engineering Dept., Bell Telephone Co. of Penna.; res., 5812 Cedarhurst St., Philadelphia, Pa.

Campbell, Edgar E., Distribution Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

***Clement, Lewis Mason**, Shift Engineer, Marconi Station, Wireless Telegraph Co., Kahuku, Oahu, T.H.

***Coup, Fred T.**, Salesman, Wagner Electric Mfg. Co., 1624 Marquette Bldg., Chicago, Ill.

Creecy, G. Eaton, Inspector, Chesapeake & Potomac Telephone Co., 106 E. Lexington St., Baltimore; res., Ilchester, Md.

Crowe, Joseph Wilkinson, Superintendent, Eagle River Electric Power Co.; res., 2830-2nd St., Baker, Ore.

Curtis, Austen M., Engineer, Western Electric Co., 463 West St., New York, N. Y.

*Curtis, Marston, Draftsman, Electrification Dept., C. M. & St. Paul Ry., Butte, Mont.

Dalton, William J., Electrical Engineer, Fisher Body Co., Detroit, Mich.

*Daly, Ralph J., Instructor in Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

*Douglass, Forrest S., Asst. Engineer, Electrical Dept., Merchants Heat & Light Co.; res., Hotel Barton, Indianapolis, Ind.

Falloon, Elisha J., Irrigation Specialist, New Business Dept., Utah Power & Light Co., 516 Kearns Bldg., Salt Lake City, Utah.

Fitzgerald, Thomas Witt, Instructor in Electrical Engineering, University of Arizona, Tucson, Ariz.

*Frankenberry, Thomas H., Meter Dept., Carolina Power & Light Co., Raleigh, N. C.

*Freygang, Walter H., Asst. to Supt. of Distribution, East River Gas Co., Long Island City, N. Y.; res., 752 Boulevard, Weehawken, N. J.

Garrett, Anthony M., Draftsman, Commonwealth Edison Co.; res., 1524 E. 61st St., Chicago, Ill.

Goebel, Rudolph C., Laboratory Assistant, Electrical Engineering Dept., University of Minnesota, Minneapolis, Minn.

*Gordon, Chester S., Plant Engineering, Southwestern Tel. & Tel. Co.; res., 333½ Guilbeau St., San Antonio, Tex.

Hale, B. K., Columbus Railway, Power & Light Co., Spring St. Station, Columbus, Ohio.

Haraguchi, Tomiichi, Testing Dept., General Electric Co.; res., 306 Germania Ave., Schenectady, N. Y.

Hardy, Norman Gladding, Master Mechanic, Arizona Copper Co., Clifton, Ariz.

Harrington, Charles A., Assistant Electrical Engineer, Mahoning & Shenango Railway & Light Co.; res., 257 Crandall Ave., Youngstown, O.

Harth, Ludwig, Supt. of Generating Sta., City of Winnipeg Hydro-Electric System, Point du Bois, P. O. Lac du Bonnet, Man.

Hatcher, C. K., Chief Operator, Puget Sound Traction Light & Power Co., Snoqualmie Falls, Wash.

Herault, P. C., Superintendent, Rome District, Georgia Railway & Power Co., Lindale, Ga.

Heybroek, Ernest, Assistant Engineer, Electrical Construction Work, Chile Exploration Corp., Chuquicamata, Chile, S. A.

Hoxie, Charles A., Asst. Elec. Engr., Standardization Laboratory, General Electric Co.; res., 44 Elm St., Schenectady, N. Y.

Isaacs, William Freeman, Foreman, Overhead & Underground Lines, Lawrence Gas Co., Lawrence, Mass.

*Jinguji, Genjiro, Choshi, Chiba Prefecture, Japan.

Johnston, Victor G., Morganton, N.C.

Kessler, Raines, Sales Engineer, Terry Steam Turbine Co.; res., 179 Whitney St., Hartford, Conn.

*Kimbell, Carl L., Construction Dept., Philadelphia Electric Co.; res., 144 N. 18th St., Philadelphia, Pa.

*Klippel, William P., Small Motor Engineer, Ft. Wayne Electric Works of G.E. Co., 26 North American Bldg., Ft. Wayne, Ind.

Lee, Charles M., Switchboardman, 74th St. Power House, Interborough Rapid Transit Co.; res., 256 W. 84th St., New York, N. Y.

*Lougee, Norman A., Consulting Engineering Dept., General Electric Co.; res., 233 Union St., Schenectady, N. Y.

Lowry, Harold K., Signal Engineer, C. R. I. & P. Ry., La Salle Station, Chicago, Ill.

MacIntosh, Redmond J., Engineering Dept., Southern Bell Tel. & Tel. Co.; res., Leland Hotel, Atlanta, Ga.

*__MacKay, Warren C.__, Draftsman, Anaconda Copper Mining Co.; res., 604 W. 4th St., Anaconda, Mont.

Meston, Archibald F., Research Engineer, Research Corp., New York; res., 1500 Wood St., Wilkinsburg, Pa.

Moore, William Johnston, Supt. of Power House, Sanitary District of Chicago, Lockport; res., 602½ Herkimer St., Joliet, Ill.

Morrison, Douglas P., Electrical Engineer, P. & L. E. R. R., Pittsburgh, Pa.

Nicholson, Charles L., Draughtsman, Toronto Hydro-Electric System; res., 199 Concord Ave., Toronto, Ont.

Olson, Martin C., A. C. Engineering Dept., General Electric Co.; res., 2 N. Wendell Ave., Schenectady, N.Y.

*__O'Neal, Josiah Philip__, Designing Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Gray Apts., Wilkinsburg, Pa.

*__Ottmer, Herman G.__, Electrical Engineer, Ann Arbor, Mich.

Paulsel, Frederic F., Electrical Engineer, Noblesville, Indiana.

Pratt, Horace Benjamin, Bureau of Engineering, Pennsylvania Public Service Comm.; res., 601 Beatty St., Pittsburgh, Pa.

Ransdall, Ralph A., Supt. of Transmission Lines, Sierra & San Francisco Power Co., 58 Sutter St., San Francisco, Cal.

Read, Ernest K., Engineering Apprentice, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 810 Franklin Ave., Wilkinsburg, Pa.

Richardson, Harvey J., Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*__Rous, Colin C.__, Assistant to Inspector of Ammunition, Ross Rifle Factory, Quebec, Que.

Sanborn, George M., Telephone Engineer, Western Electric Co., New York; res., 1034 Broad St., Newark, N. J.

Skidmore, Ernest W., Lawrenceburg, Tenn.

Slater, J. Herbert, Electrician, Paraffine Paint Co., Emeryville; res., 1402 Spruce St., Berkeley, Cal.

Stahl, Charles Raymond, Chief Engineer, E. E. White Coal Co. Stotesbury, W. Va.

Stevenson, Edward E., Draftsman, Mechanical Engineer's Office, Los Angeles Hall of Records; res., 403 Brooks Ave., Venice, Cal.

Straw, J. B., Instructor in Electrical Engineering, University of Pennsylvania Philadelphia, Pa.

Sykes, Charles S., Electrical Engineer, General Electric Co.; res., 2041 So. 57th St., Philadelphia, Pa.

Tuttle, Ralph Everett, Electric Power House Construction, United Electric Light Co.; res., 22 Winthrop St., Springfield, Mass.

Walters, James N., Engineering Dept., New York Telephone Co., 15 Dey St., New York; res., 245 Martense St., Brooklyn, N. Y.

*__Walton, Joseph N.__, General Electric Co.; res., 45 Forrest Place, Pittsfield, Mass.

Wilder, Harry Converse, Secretary, Malone Light & Power Co., 8 E. Main St., Malone, N. Y.

Williams, Leroy C., Assistant to Engineer in charge of Substations, Pacific Gas & Electric Co., 801 Grant Bldg., San Francisco, Cal.

Williamson, Arba G., Signal Engineer, Automatic Train Control & Signal Co., 7077 Jenkins Arcade Bldg., Pittsburgh, Pa.

Williamson, Bert A., Electrolysis Inspector, Los Angeles Gas & Electric Corp.; res., 1760 W. 39th St., Los Angeles, Cal.

*__Wood, Daniel Charles__, Service Inspector, State Public Utilities Commission of Illinois, 714 Insurance Exchange Bldg., Chicago, Ill.

*__Yates, J. E.__, Pacific Power & Light Co., Spalding Building, Portland, Ore.

Total 82

*Former enrolled students.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1915.

Baird, H. B., Hagerstown, Md.
Bell, W. R., Millbury, Mass.
Blaney, L. W., Gatun, C. Z.
Chapman, P. E., San Francisco, Cal.
Collins, J. D., Philadelphia, Pa.
Conwell, R. N., Newark, N. J.
Cory, M. M., E. Lansing, Mich.
Danner, J. R., Rancagua, Chile
Dash, C. C., Cleveland, Ohio.
Donohue, J. F., Chucquicamata, Chile
Fondiller, W. (Member), New York, N.Y.
Guy, G. L. (Member), Winnipeg, Man.
Haig, W. A., Jr., Milwaukee, Wis.
Hasegawa, T., Tokyo, Japan
Hausen, R. F., Pittsburgh, Pa.
Howe, C. S. (Fellow), Cleveland, O.
Humiston, J. M., Chicago, Ill.
Iengar, N. N., Bangalore, India.
LaMotte, W. R., Newark, N. J.
Lindstrom, N. G. G. (Member), Cleveland, O.
Macqueen, J. A., Winnipeg, Man.
Maher, H. L., Detroit, Mich.
Malby, S. G., New York, N. Y.
McGahey, C. R., Baltimore, Md.
Minton, J. P., Pittsfield, Mass.
Muldaur, G. B., New York, N. Y.
Neblett, H. W., Chicago, Ill.
Ohlsson, F. S. (Member), Elkhorn, Wis.
Perham, D. M., Cedar Rapids, Iowa.
Ramsey, H. E., Lansford, Pa.
Rindflish, F. C., Detroit, Mich.
Roesler, G. A., Englewood, S. D.
Ross, R. H., Waratah, Tasmania.
Roth, H. C., Joplin, Mo.
Rowe, E. C., Chicago, Ill.
Sanford, D., Grace, Idaho.
Schertz, W. A. (Member), Milwaukee, Wis.
Schmiech, C. A., Chicago, Ill.
Skove, W., Cleveland, Ohio.
Smith, J. U., San Francisco, Cal.
Stephens, H. H., Philadelphia, Pa.
Tanzer, E. D., Easton, Pa.
Thomson, G. L. A., Newark, N. J.
Turnbull, W. H., Jr., Woodbury, N. J.
Watson, T. A. (Fellow), Boston, Mass.
Whitall, R. C., Westerly, R. I.
Williams, R. G. H., Bridgeport, Conn.
Wrench, R. A., Rancagua, Chile.

Total 48.

Students Enrolled March 12, 1915

7214 Lindsey, G. H., Univ. of Illinois.
7215 Paffenbarger, R. S., Ohio St. Univ.
7216 Stephenson, H.M., Ohio Nor. Univ.
7217 White, T. K., Univ. of Illinois
7218 Diefenderfer, I. C., Pa. State Coll.
7219 Roberts, B. H., Washington Univ.
7220 Butcher, A.M., Kans. State Ag. Coll.
7221 Andrews, R.D., Throop Coll. Tech.
7222 Orahood, L.O., Armour Inst. Tech.
7223 Potter, J. V., Montana State Coll.
7224 Owens, R. W., Univ. of Illinois
7225 Baker, D. B., Mass. Inst. Tech.
7226 Beverage, H. H., Univ. of Maine.
7227 Brown, B. B., Va. Poly. Inst.
7228 May, A. D., Syracuse University.
7229 Parsons, G. M., Syracuse Univ.
7230 Woolfolk, R. B., Columbia Univ.
7231 Reasner, G. C., Purdue Univ.
7232 Heggenberger, L. E., Highland Park College
7233 Talcott, W.W., Highland Pk. Coll.
7234 Andrade, R.R., Highland Pk. Coll.
7235 Craven, B. E., Highland Pk. Coll.
7236 Hawkins, E. R., Univ. of Idaho.
7237 Coy, J. A., Syracuse University.
7238 Dicke, L. E., Lewis Institute.
7239 Benson, J. D., Iowa State College.
7240 Peterson, J., Purdue University.
7241 Noble, S. E., Penna. State Coll.
7242 Gourley, R. L., Penna. State Coll.
7243 Murray, F. J., Cooper Union.
7244 Jones, H. D., Univ. of Penna.
7245 Johnson, F. B., Univ. of Texas.
7246 Brown, W. E., Jr., Univ. of Texas.
7247 Jacobs, H. S., Univ. of Texas.
7248 Davies, J. B., Jr., Univ. of Texas.

7249 Holbrook, H. T., Univ. of Texas.
7250 Murphy, J. R., Va. Poly. Inst.
7251 Bennett, C. B., Cornell Univ.
7252 Lockwood, L. D., Cornell Univ.
7253 de la Roza, J., Cornell Univ.
7254 Bergstresser, H. F., Lehigh Univ.
7255 Gardner, A. B., Harvard Univ.
7256 Summers, A. R., Univ. of Illinois.
7257 Bauer, C. O., Purdue University.

Total 44.

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than 50 words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Vacancies

V-61. Opportunity in New York territory for a technical graduate who has had experience in the operation of direct-current machinery, preferably one who has been through the Westinghouse or General Electric test, and who has been employed as a salesman.

The United States Civil Service Commission announces an open competitive examination for mine electrician, for men only, on April 28, 1915, to be held at numerous places in the U. S. From the register of eligibles resulting from this examination, certification will be made to fill a vacancy in this position in the Bureau of Mines, Department of the Interior, for service in the field, at a salary ranging from $1,200 to $1,500 a year, and vacancies as they may occur in positions requiring similar qualifications, unless it is found to be in the interest of the service to fill any vacancy by reinstatement, transfer, or promotion.

The duties of this position will be to make investigations bearing upon the safety of electricity in mines and the causes of mine disasters for which electricity may have been responsible. The duties will involve considerable field work and travel. At least one year's study of electrical applications in a technical school of recognized standing and five years in actual underground electrical work in mines, are prerequisites for consideration for this position.

Persons who meet the requirements and desire this examination should at once apply for the circular announcing this examination (Form No. 297, issued March 20, 1915) and Form 1312, stating the title of the examination for which the form is desired, to the United States Civil Service Commission, Washington, D. C.

Men Available

233. Construction Engineer. Thirteen years' experience in the construction and maintenance of all types of transmission lines, distributing systems and substations. Can handle any proposition demanding executive and organizing ability. Last six years with large corporation in the west. Single; age 32.

234. Electrical Engineer. Cornell graduate. Fifteen years' experience, mostly in the invention, development and manufacture of telegraphic, telephonic and other signaling devices. Has had business and installation experience, and has traveled extensively. Desires executive or engineering position.

235. Mechanical and Electrical Engineer. Experience includes four-year apprentice course, machine trade, with Baldwin Locomotive Works; eighteen months testing department Westinghouse Elec. & Mfg. Co., also drawing room, rate and estimating departments.

236. Practical all-round electrician with technical education, desires position of responsibility. Married; age 28; ten years' experience power house wiring, interior wiring, operating, high-tension station work, etc. Specially familiar with high-tension work up to

100,000 volts. Good repairman; can handle men. Will go anywhere.

237. Electrical Engineer. 1914 graduate. Desires position with manufacturing, public service or commercial firm. Willing to start at bottom; salary not important. Desires permanent location; not particular as to locality. Does not use tobacco or liquor.

238. Electrical Engineer. Mem. A. I. E. E., Mem. A. S. M. E. Sixteen years' experience embracing drafting, design of power plants, transmission systems; illuminating and electrical engineering in connection with industrial plants, with a considerable amount of steam engineering. Six years in responsible charge.

239. Electrical Engineer and Sales Representative. Age 34; married. Eighteen years' experience—shop, constructing and operating hydroelectric, steam, gasoline, Diesel, ice plants, and sales engineering. Familiar with Allis-Chalmers, G. E. and Westinghouse apparatus. Willing to go to foreign country. Can handle Oriental labor.

240. Distribution Engineer. 25 years' experience in design, construction and maintenance of aerial and underground distribution systems. Thoroughly competent to design and build underground systems. Practical experience in handling all types of cable. Fair estimator.

241. Electrical-Mechanical Engineer. Desires responsible position as assistant manager of commercial or industrial plant located in or near Boston. Graduate Mass. Inst. Tech., married, and at present employed as an industrial safety engineer. Broad practical experience which includes office work, machine shop practise, inspection work and the design of safe-guards.

242. Young man, 30, experienced in underground distribution, supervision of cable work, conduit work, map, record and office requirements, testing, planning, etc., desires change.

243. Electrical Engineer. Graduate (1911) Univ. Penn. Married. Four years with Electric Storage Battery Co.; desires position in electrical field where good experience may be obtained and hard work will be rewarded with advancement. Pay to start immaterial. Would prefer position in or near New York or Philadelphia.

244. Electrical Engineer. Twelve years' experience in design, construction and management of electric light, power and railway properties. Thoroughly familiar with estimates, reports, accounting systems, rates, etc. Has held positions of designing engineer, construction superintendent, and general manager. Capable of handling employes and successful in dealing with the public.

245. Electrical Engineer. Technical graduate; age 24. Desires position with light and power company, telephone company, or with consulting engineer. Eighteen months draftsman and assistant field engineer with telephone company; several months with light and power company as draftsman. Salary no consideration if position offers opportunity for advancement.

246. Technical Graduate, (1912 Sheff.) Would like to obtain a position with construction or consulting engineer. Three years test experience with motors and transformers. No objection to foreign service.

247. Mechanical - Electrical Engineer. Three years shop erecting and installations; six years drafting, supervising, assisting electrical and mechanical engineering departments on gas engines, crude-oil engines, generators, motors, controllers and switchboards; also experience in automobile lighting, starting, ignition and gear shift. Thoroughly reliable and energetic. Speak several languages.

248. Electrical Engineer. Technical graduate; six years' experience General Electric Test, switchboard operator and designing engineer. Any kind of electrical work with chance of advancement acceptable.

249. Electrical Engineer. Twelve years' experience—three years in Europe and nine years with American firm; desires to be representative for Italy of American electrical concern. English, French, German, Italian, Spanish languages well known.

250. Experienced salesman, business man and engineer, desires position where it will not be necessary to travel. Sales experience with large electrical manufacturing companies. Technical and university graduate. Prefer commercial or other department of public service company.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Aufgaben und Lösungen aus der Gleich und Wechselstromtechnik ed. 4. By H. Vieweger. Berlin. 1914. (Purchase.)

Bow River Power and Storage Investigations. (Canada Water Power Branch, Water Resources Paper no. 2) Ottawa, 1914. (Gift of Canada Water Power Branch.)

Development of water power. (U. S. Senate. 63d Congress, 3d session) Washington, 1915. (Gift of Senate.)

Edison Phonograph Works, Report on fire, Dec. 9, 1914. Prepared jointly by National Fire Protection Association and National Board of Fire Underwriters. Jan. 30, 1915. (Gift of National Fire Protection Association.)

Electric Vehicle Hand-book. Ed. 2. By H. C. Cushing, Jr. New York, 1914. (Purchase.

Elementary Electricity and Magnetism. By W. S. Franklin and Barry Macnutt. New York, The Macmillan Co. 1914. (Gift of authors.) Price $1.25 net.

Advanced Theory of Electricity and Magnetism. By W. S. Franklin and Barry MacNutt. New York, The Macmillan Co., 1915. (Gift of authors.) Price $2.00.

The authors, professors in Lehigh University, have issued these two text books, with the idea in mind to put the essentials of electrical knowledge in the first volume, a primer; and put the theory, stripped of abstruse mathematics, in the second. " The character of the treatment in this book (the second) has been determined throughout by the desire to keep the student's mind jammed up tight against physical things."

Numerous problems are given in both books.
W.P.C.

La Elettrificazione delle Ferrovie. By Aldo Righi. Bologna, n.d. (Gift of Nicola Zanichelli.)

Gas, Electric and Street Railway Association of Oklahoma. Proceedings of Annual Convention. 2d, 3d. Oklahoma, 1913, 1914. (Gift of Association.)

Graphite. vol. 16, 1914. Jersey City, 1914. (Gift of Joseph Dixon Crucible Co.)

Grundzüge des Ueberspannungsschutzes in Theorie und Praxis. By Karl Kuhlmann. Berlin, 1914. (Purchase.)

Impianti Elettrici a Correnti Alternate. By Attilio Marro. Milano, 1914. (Purchase.)

Institution of Engineers of the River Plate. Bateman Legacy. Buenos Aires, 1914.

——Calculation of Timber Columns. Buenos Aires, 1913.

——Development of the City of Buenos Aires Water Supply Works. Buenos Aires, 1914.

——Talk about Refrigeration and its General Application. Buenos Aires, 1914.

——Yearly Report Balance and List of Members 1913-14 Buenos Aires, 1914. (Gift of Institution of Engineers of the River Plate.)

Los Angeles. Board of Public Utilities. Annual Report 5th, 1913-14. (Gift of Board of Public Utilities, Los Angeles.)

Manitoba Water Powers. (Canada. Water Power Branch, Water Resources Paper no. 7) Ottawa, 1914. (Gift of Canada Water Power Branch.)

Manual of Wireless Telegraphy (Radio) for the use of Naval Electricians. By S. S. Robinson. Ed. 3. Annapolis, Md., 1913. (Purchase.)

Modern Electrical Theory. Ed. 2. By Norman Robert Campbell. Cambridge, 1913. (Purchase.)

Motion Picture Electricity. By J. H. Hallberg. New York, 1914. (Purchase.)

Municipal Engineering. Aug. 1913. (Purchase.)

Naval Electricians Text Book Ed. 3. Vol I-Theoretical. By W. H. G Bullard. Annapolis, 1915. (Purchase.)

New York State. Public Service Commission for the First District. Report, vol. I, 1913. Albany, 1914. (Exchange.)

Notes on the Water Supply of Greater New York. By Wm. T. Taylor. Reprinted from Transactions of Society of Engineers, 1914. (Gift of author.)

Smithsonian Physical Tables. Ed. 6. Washington, 1914. (Purchase.)

Technical and Hydro-electric and Transmission Section. Features of design of high-tension transmission systems, with table. By Selby Haar. (Read before the National Electric Light Association, 37th Convention, June 1-5, 1914.) (Gift of author)

Telegraph Engineering. By Erich Hausmann. New York, 1915. (Gift of D. Van Nostrand Co.) Price $3.00 net.

The book is the out-growth of Professor Hausmann's lectures at the Brooklyn Polytechnic Institute. It treats of simplex. duplex, and quadruplex telegraphy; automatic and printing telegraphs; municipal and railroad systems; transmission lines and cables; and submarine telegraphy.
W.P.C.

Text Book of Physics—Electricity and Magnetism. By J. H. Poynting and J. J. Thomson. London, 1914. (Purchase.)

Transmission Line Construction—Methods and Costs. By R. A. Lundquist. New York, 1912. (Purchase.)

Travaux du Laboratoire Central d'Electricité. Tome III, 1912-13. By P. Janet. (Société Internationale des Electriciens) Paris, 1914. (Exchange.)

Vermont. Public Service Commission. Biennial Report, 14th, 1912-14. Bellows Falls, 1914. (Gift of Commission.)

TRADE CATALOGUES

Allgemeine Elektricitäts Gesellschaft. Berlin, Germany. Nitra-u. Spiraldraht Lampen fur Photographie Kinematographie und Projektion.

Chicago Pneumatic Tool Co. Chicago, Ill. Ideal Power. Feb. 1915.

Leeds & Northrup Co. Philadelphia, Pa. Macbeth Illuminometer. 16 pp.

Ohio Brass Co. Mansfield, Ohio. O-B Bulletin Jan.-Feb. 1915.

UNITED ENGINEERING SOCIETY

American Manufacturers Export Association. Year Book, 1914. New York, 1914. (Gift of Association.)

American Year Book, 1914. New York-Lond. 1915. (Purchase.)

Brown's Directory of American Gas Companies. 1914. New York. 1914. (Purchase.)

Carnegie Library of Pittsburgh. Men of Science and Industry. A guide to the biographies of scientists, engineers, inventors and physicians. Pittsburgh, 1915. (Gift of Carnegie Library of Pittsburgh.)

Collection of Papers written by Geo. F. Kunz. (Gift of author.)

Construction of Masonry Dams. By Chester W. Smith. New York, 1915. (Purchase.)

Cushing's Manual of Parlimentary Law and Practice. Revised and enlarged by C. K. Gaines. Boston-New York, 1912. (Purchase.)

Die Dampfkessel. Ed. 3. By F. Tetzner. Berlin, 1907. (Purchase.)

Dewey Decimal Classification. Ed. 8. Lake Placid Club, N. Y. 1913. (Purchase.)

Eagle Almanac, 1915. Brooklyn-New York, 1915. (Purchase.)

Economics of Business. By N. A. Brisco. New York, 1913. (Purchase.)

Einführung in die Organisation von Maschinenfabriken. By F. Meyenberg. Berlin, 1913. (Purchase.)

Engineering Geology. By Heinrich Ries and T. L. Watson. New York, 1914. (Purchase.)

Entwerfen einfach bewehrter Eisenbetonplatten. By M. Preuss. Berlin, 1914. (Purchase.)

Electric Vehicle Association of America Papers, Reports and Discussions of 2d Annual Convention. 1911. (Gift of Association.)

Electrical Patents, 1914. (Gift of Robt. S. Allen.)

Die elektrischen Metallfadengluhlampen. By C. H. Weber. Leipzig, 1914. (Purchase.)

Ermittlung der billigsten Betriebskraft für Fabriken. By Karl Urbahn. Ed. 2, by Ernst Reutlinger. Berlin, 1913. (Purchase.)

Handbuch für Eisenbetonbau. Band 11, Ed. 2. By F. von Emperger. Berlin, 1915. (Purchase.)

Jahrbuch der Technischen Zeitschriften Literatur für die Literaturperiode 1913. Berlin, 1914. (Purchase.)

Kansas Gas, Water, Electric Light and Street Railway Association. Proceedings of annual meeting. 13th, 16th. 1910, 1913.

Kansas Gas, Water Electric Light and Street Railway Association. Official Convention Proceedings. 17th Annual meeting, 1914. (Gift of Association.)

Das Leuchten der Gase und Dampfe. By Heinrich Konen. (Die Wissenschaft, Band 49.) Braunschweig, 1913. (Purchase.)

Manual of Corporate Organization. Ed. 3. By Thomas Conyngton, New York, 1913. (Purchase.)

Die Methoden der Massanalyse. By H. Beckurt Braunschweig, 1913. (Purchase.)

Michigan Gas Association. Proceedings of 23d Annual Meeting 1914. (Gift of Association.)

New York Times Index, vol. IV, 1914. New York, 1914. (Purchase.)

Pennsylvania, First Industrial Directory, 1913. Harrisburg, 1914. (Gift of Department of Labor and Industry.)

Praktisches Handbuch der Fabrikation und Bearbeitung des Stahls. By Damemme. Leipzig, 1839. (Purchase.)

Preservation of Structural Timber. By H. F. Weiss. New York, 1915. (Purchase.)

Prometheus. vols. 1-19, 1889-1908. Berlin, 1890-1909. (Purchase.)

Red Book. A text book on U. S. gypsum products for architects, contractors, plasterers and U. S. G. dealers. 1914. Chicago, 1914. (Gift of U. S. Gypsum Company.)

Taschenbuch der Luftflotten. 2 Jahrgang 1915. München, 1915. (Purchase.)

United States Cast Iron Pipe and Foundry Company. Catalogue, 1914. Burlington, N. J. 1914. (Gift of Company.)

Use of Water in Irrigation. By Samuel Fortier. New York, 1915. (Purchase.)

Utilization of Waste Products. Ed. 2. By Theodorr Koller. London, 1915. (Purchase.)

World Almanac and Encyclopedia, 1915. New York, 1915. (Purchase.)

Zeitschrift für Physikalische Chemie. Band. 83 86. Leipzig, 1913-14. (Purchase.)

Das Zelluloid und seine Ersatzstoffe. By S. Feitler. Wein, 1912. (Purchase.)

GIFT OF WM. J. HAMMER

An Epitome of the work of the Aeronautic Society, from July 1908-Dec. 1909. (Bulletin No. 1.)

Aeronautic Society. Constitution & By-Laws.

Program of 1st Annual Banquet of Aeronautical Society. Apr. 27, 1911.

Official Program of Exhibition and Tournament, Morris Park, Nov. 3, 1908, June 26, 1909.

Announcement of Jamestown Aeronautical Congress, Oct. 28, 29, 1907, Norfolk, Va.

Pamphlets and periodicals containing articles written by Wm. J. Hammer (14).

OFFICERS AND BOARD OF DIRECTORS, 1914-1915

PRESIDENT.

(Term expires July 31, 1915.)
PAUL M. LINCOLN.

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1915.)	(Term expires July 31, 1916.)
RALPH D. MERSHON.	C. O. MAILLOUX.

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(Term expires July 31, 1915.)	(Term expires July 31, 1916.)
J. A. LIGHTHIPE.	F. S. HUNTING.
H. H. BARNES, JR.	N. W. STORER.
C. E. SCRIBNER.	FARLEY OSGOOD.

MANAGERS.

(Term expires July 31, 1915.)	(Term expires July 31, 1916.)	(Term expires July 31, 1917.)
COMFORT A. ADAMS.	H. A. LARDNER.	FREDERICK BEDELL.
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WILLIAM B. JACKSON.	PETER JUNKERSFELD.	A. S. McALLISTER.
WILLIAM McCLELLAN.	L. T. ROBINSON.	JOHN H. FINNEY.

TREASURER.	(Term expires July 31, 1915.)	SECRETARY.
GEORGE A. HAMILTON.		F. L. HUTCHINSON.

HONORARY SECRETARY.	LIBRARIAN.
RALPH W. POPE.	W. P. CUTTER.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

PAST-PRESIDENTS.—1884-1914.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.

*Deceased.

STANDING COMMITTEES

Revised to April 1, 1915

EXECUTIVE COMMITTEE.

P. M. Lincoln, Chairman,
W. E. and M. Company, East Pittsburgh, Pa
C. A. Adams,
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Harold Pender,
W. I. Slichter.

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E. E. F. Creighton,
A. F. Ganz,
Dugald C. Jackson,
William B. Jackson,
V. Karapetoff,
S. M. Kintner,
C. S. McDowell,
H. H. Norris,
J. C. Reed,
D. B. Rushmore,
C. E. Scribner,
Clayton H. Sharp,
Charles P. Steinmetz,
H. G. Stott,
Wilfred Sykes,
P. H. Thomas,
J. B. Whitehead.

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239 West 39th St., New York.
M. G. Lloyd,
A. S. McAllister,
W. S. Rugg,
W. I. Slichter.

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165 Broadway, New York.
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John B. Taylor.

SECTIONS COMMITTEE.

H. A. Hornor, Chairman,
Hamilton Court, 39th and Chestnut Streets
Philadelphia, Pa.
Frederick Bedell,
H. W. Flashman,
W. A. Hall,
F. D. Nims,
Charles F. Scott,
and the chairmen of all Institute Sections.

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Revised to April 1, 1915

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Appointed by President for terms of five years.

Term expires July 31, 1919.

Charles F. Brush, William Stanley,
N. W. Storer.

Term expires July 31, 1918.

H. W. Buck, F. A. Scheffler.
J. Franklin Stevens,

Term expires July 31, 1917.

A. E. Kennelly, Robert T. Lozier.

Term expires July 31, 1916.

Ralph D. Mershon, Frank J. Sprague,
Schuyler Skaats Wheeler, Chairman,
Ampere, N. J.

Term expires July 31, 1915.

J. W. Lieb, E. L. Nichols.
Elihu Thomson,

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.

C. O. Mailloux, L. T. Robinson.
C. E. Scribner,

Term expires July 31, 1915.

H. H. Barnes, Jr., A. S. McAllister.
William McClellan,

Ex-Officio.

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George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

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The chairman of the Institute's Code Committee,

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON ADVISORY BOARD, NATIONAL CONSERVATION CONGRESS.

Calvert Townley.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON AMERICAN ELECTRIC RAILWAY ASSOCIATION'S COMMITTEE ON JOINT USE OF POLES.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman.
Paul Winsor.

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And the President and Secretary of the Institute.

ON JOINT COMMITTEE ON LEGISLATION RELATIVE TO REGISTERING ENGINEERS.

William McClellan, S. D. Sprong.

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Guido Semenza, N. 10, Via S. Radegonda, Milan, Italy.
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L. A. Herdt, McGill Univ., Montreal Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5 Schoeneberg, Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff, Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co. Ltd., Bombay, India.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux.
Clayton H. Sharp.

LIST OF SECTIONS

Revised to April 1, 1915.

Name and when Organized.		Chairman	Secretary.
Atlanta	Jan. 19, '04	A. M. Schoen	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts, Industrial Building, Baltimore, Md.
Boston	Feb. 13, '03	G. W. Palmer, Jr.	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago	1893	E. W. Allen	W. J. Norton, 112 W. Adams St., Chicago, Ill.
Cleveland	Sept. 27, '07	Howard Dingle	R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio.
Detroit-Ann Arbor	Jan. 13, '11	H. H. Norton	Ray K. Holland, Cornwell Building, Ann Arbor, Mich.
Fort Wayne	Aug. 14, '08	L. D. Nordstrum	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Indiana.
Indianapolis-Lafayette	Jan. 12, '12	J. L. Wayne, 3rd.	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Los Angeles	May 19, '08	C. G. Pyle	Edward Woodbury, Pacific Lt. & Pr. Company, Los Angeles, Cal.
Lynn	Aug. 22, '11	W. H. Pratt	F. S. Hall, General Electric Co., Lynn, Mass.
Madison	Jan. 8, '09	J. W. Shuster	F. A. Kartak, Univ. of Wisconsin, Madison Wis.
Mexico	Dec. 13, '07		
Milwaukee	Feb. 11, '10	L. L. Tatum	W. J. Richards, National Brake and Electric Co., Milwaukee, Wis.
Minnesota	Apr. 7, '02	Leo H. Cooper	Emil Anderson, 1236 Plymouth Bldg., Minneapolis, Minn.
Panama	Oct. 10, '13	Hartley Rowe	Clayton J. Embree, Balboa Heights, C. Z.
Philadelphia	Feb. 18, '03	H. F. Sanville	W. F. James, 1115 North American Bldg., Philadelphia, Pa.
Pittsburgh	Oct 13, '02	J. W. Welsh	Charles R. Riker, Electric Journal, Pittsburgh, Pa.
Pittsfield	Mar. 25, '04	W. W. Lewis	M. E. Tressler, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	R. F. Monges	Paul Lebenbaum, 45 Union Depot, Portland, Ore.
Rochester	Oct. 9, '14	John C. Parker	O. W. Bodler, Pittsford, N. Y.
St. Louis	Jan. 14, '03	S. N. Clarkson	W. O. Pennell, Southwestern Bell Tel. System, St. Louis, Mo.
San Francisco	Dec. 23, '04	C. J. Wilson	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady	Jan. 26, '03	H. M. Hobart	S. M. Crego, Gen. Elec. Co. Schenectady, N. Y.
Seattle	Jan. 19, '04	S. C. Lindsay	E. A. Loew, University of Washington, Seattle, Wash.
Spokane	Feb. 14, '13	J. W. Hungate	L. N. Rice, Spokane and Inland Empire R. R. Co., Spokane, Wash.
Toledo	June 3, '07	George E. Kirk	Max Neuber, Cohen, Friedlander & Martin, Toledo, O.
Toronto	Sept. 30, '03	D. H. McDougall	H. T. Case, Continental Life Bldg., Toronto. Ont.
Urbana	Nov. 25, '02	I. W. Fisk	P. S. Biegler, Univ. of Illinois, Urbana, Ill.
Vancouver	Aug. 22, '11	E. P. LaBelle	K. C. Auty, B. C. Electric Railway Co., Ltd., Vancouver, B. C.
Washington, D. C.	Apr. 9, '03	C. B. Mirick	C. A. Peterson, 1223 Vermont Ave., N. W. Washington, D. C.

Total 31

LIST OF BRANCHES

Name and when Organized.		Chairman	Secretary.
Agricultural and Mech. College of Texas	Nov. 12, '09	J. F. Nash	A. Dickie, A. & M. College, College Station, Texas.
Alabama, Univ. of	Dec. 11, '14	W. M. Johnston	L. M. Smith, University, Ala.
Arkansas, Univ. of	Mar. 25, '04	D. C. Hopper	J. E. Bell, Univ. of Arkansas, Fayetteville, Ark.
Armour Institute	Feb. 26, '04	W. L. Burroughs	Chester F. Wright, 3341 Michigan Boulevard, Chicago, Ill.
Bucknell University	May 17, '10	R. K. Hoke	George A. Irland, Bucknell University, Lewisburg, Pa.
California Univ. of	Feb. 9, '12	L. R. Chilcote	E. S. Meddaugh, 2521 Channing Way, Berkeley, Cal.
Cincinnati, Univ. of	Apr. 10, '08	F. Oberschmidt	A. C. Perry, 707 East McMillan Street, Cincinnati, O.
Clemson Agricultural College	Nov. 8, '12	W. E. Blake	F. L. Bunker, Clemson College, S. C.
Colorado State Agricultural College	Feb. 11, '10	G. M. Strecker	E. O. Marks, Colorado State Agricultural College, Fort Collins, Colo.

LIST OF BRANCHES—Continued.

Name and when Organized.	Chairman	Secretary
Colorado, Univ. of...... Dec. 16, '04	Philip S. Borden	Charles S. Miller, University of Colorado, Boulder, Colo.
Georgia School of Technology.............. June 25, '14	R. A. Clay	J. M. Reifsnyder, Jr., Georgia School of Technology, Atlanta, Ga.
Highland Park College.. Oct. 11, '12	Clyde Prussman	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa.
Idaho, University of.... June 25, '14	E. R. Hawkins	C. L. Rea, University of Idaho, Moscow, Idaho.
Iowa State College...... Apr. 15, '03	Roscoe Schaffer	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.......... May 18, '09		A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col.,.. Jan. 10, '08	L. V. Fickle	Clarence E. Reid, Kansas State Agric. Col., Manhattan, Kan.
Kansas, Univ. of....... Mar. 18, '08	Ray Walker	Ernest Arnold, Univ. of Kansas, Lawrence, Kansas.
Kentucky State, Univ. of Oct. 14, '10	Harry Y. Barker	G. F. Campbell, 345 South Limestone Street, Lexington, Ky.
Lafayette College....... Apr. 5, '12	R. McManigal	W. J. English, Jr., Lafayette College, Easton, Pa.
Lehigh University...... Oct. 15, '02	N. F. Matheson	F. C. Brockman, 3 North Main St., Nazareth, Pa.
Lewis Institute......... Nov. 8, '07	A. H. Fensholt	Fred A. Rogers, Lewis Institute, Chicago, Ill.
Maine, Univ. of........ Dec. 26, '06	H. H. Beverage	W. E. Bowler, University of Maine, Orono, Maine.
Michigan, Univ. of...... Mar. 25, '04	H. A. Enos	H. W. Stubbs, University of Michigan, Ann Arbor, Mich.
Missouri, Univ of.,...... Jan. 10, '03	E. W. Kellogg	K. Atkinson, University of Missouri, Columbia, Mo.
Montana State Col.,.... May 21, '07	John M. Fiske	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of..... Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A. Lincoln, Nebr.
New Hampshire Col..... Feb. 19, '09		
North Carolina Col. of Agr., and Mech. Arts...... Feb. 11, '10	H. M. Alexander	D. G. McArn, West Raleigh, N. C.
North Carolina, Univ. of Oct. 9, '14	P. H. Daggett	J. W. McIver, University of North Carolina, Chapel Hill, N. C.
Ohio Northern Univ... Feb. 9, '12	R. E. Lowe	W. F. Schott, 426 South Union Street, Ada, Ohio.
Ohio State Univ.,....... Dec. 20, '02	Leslie J. Harter	Robert C. Schott, 38 14th Avenue, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col........... Oct. 13, '11	J. C. Woodson	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of..... Oct. 11, '12	C. K. Karcher	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon, Agr. Col.,...... Mar. 24, '08	W. R. Grasle	Winfield Eckley, Oregon Agric. Col., Corvallis, Ore.
Penn State College...... Dec. 20, '02	W. L. Kirk	A. C. Horst, State College, Pa.
Pittsburgh, Univ. of.,... Feb. 26, '14	G. W. Flaccus	Ralph C. Zindel, University of Pittsburgh, Pittsburgh, Pa.
Purdue Univ.,........... Jan. 26, '03	L. W. Spray	R. E. Tafel, Purdue Univ., Lafayette, Ind.
Rensselaer Poly. Inst..... Nov. 12, '09	W. J. Williams	W. E. Coover, 74 Eagle Street, Troy, N. Y
Rose Polytechnic Inst., Nov. 10, '11	Warren F. Turner	F. Edward Bundy, 1103 N. 8th Street, Terra Haute, Ind.
Rhode Island State Col. Mar. 14, '13	W. C. Miller	P. M. Randall, Jr., Rhode Island State College, Kingston, R. I.
Stanford Univ.,........ Dec. 13, '07	G. L. Beaver	H. J. Scholz, Stanford University, Cal.
Syracuse Univ.,........ Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.,........ Feb. 14, '08	J M. Bryant	J. A. Correll, University of Texas, Austin, Tex.
Throop College of Technology.............. Oct. 14, '10	R. S. Ferguson	W. M. Holmes, Throop Poly. Institute, Pasadena, Cal.
Virginia Polytechnic Institute............... Jan. 8, '15	M. F. Peake	J. R. Murphy, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of....... Feb. 9, '12	W. S. Rodman	H. Anderson, Jr., 1022 West Main St., Charlottesville, Va.
Wash. State Col. of.... Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash., Pullman, Wash.
Washington Univ....... Feb. 6, '04	C. C. Hardy	Charles P. Seeger, Washington University, St. Louis, Mo.
Washington, Univ. of.,.. Dec. 13, '12	H. W. McRobbie	B. B. Bessesen, Univ. of Washington, Seattle, Wash.
West Virginia Univ..... Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly. Inst.,... Mar. 25, '04	Frank Aiken	A. B. R. Prouty, Worcester Poly. Inst., Worcester, Mass.
Yale University........ Oct. 13, '11	F. M. Doolittle	K. Lessey, 106 Van Sheff. New Haven, Conn.

Total 52.

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of the

American Institute

of

Electrical Engineers

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THE FLOW OF ENERGY

BY ROBERT A. PHILIP

ABSTRACT OF PAPER

A new graphical method of representing the flow of energy is described and pictures are drawn showing the functions of generators, motors, transformers, transmission lines and other parts of an electric distributing system in terms of the flow of energy through them.

The method is based on using two ribbons; one to represent the flow of energy proper, and the other (not used for direct currents) representing the magnetizing power. It is shown that various phenomena of alternating-current transmission are determined by the widths and directions of the two ribbons.

The principal elements of the picture (generators, synchronous motors, induction motors, etc.) are taken up one by one and in simple combinations, each case being illustrated by typical figures.

THE flow of a material fluid, such as water or air, through the pipes which transmit it may be shown as a ribbon whose varying width represents the variations of the current.

A similar picture may be drawn of the transmission of power. It is, however, more exact to consider that it is energy rather than power which is being transmitted because power means a flow of energy. The relation between power and energy is similar to that between a current of water and the water itself. That is, power is a name for a current of energy.

Energy like matter can be transported or changed in form but can be neither created nor destroyed. Therefore in the distribution of energy as in the distribution of a material fluid the total quantity supplied to the distributing system, plus or minus storage in the system itself, must at every instant equal the quantity delivered, including leakage. This fundamental similarity allows a distribution of energy to be pictured as though it was a distribution of matter.

Fig. 1 is a picture, on this basis, of the flow of energy into, through and out of a rotating shaft. Along the route of the shaft a ribbon is drawn, the width of the ribbon at each point being proportional to the flow of energy, that is the power, at

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that point. Evidently, if there is no storage in the shaft the width of the ribbon can only increase at points where energy flows in and only decrease where it flows out and a change in width of the ribbon representing the main stream of energy must be exactly equal to the width of a branch at that point. The flow of energy may be measured in any convenient unit, hors epower, foot-pounds per second or kilowatts, and the width of the ribbon may be drawn to any desired scale. At each point the flow has two elements, amount and direction, the former being represented by the width of the ribbon and the latter indicated by arrows marked on the ribbon.

This first illustration is based on the transmission of energy through a rotating shaft where the energy comes in and goes out over moving belts and is lost in bearing friction. A similar illustration may be used for the hydraulic and pneumatic transmission of energy by currents of water and of air and for the electric transmission by electric current.

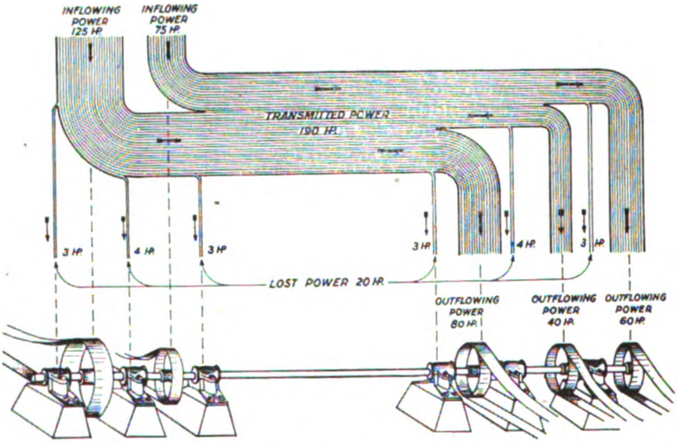

FIG. 1—FLOW OF ENERGY THROUGH A SHAFT

The picture drawn is a general one and may be used to represent the transmission of any kind of energy in any manner. Energy may be transmitted in one form, transformed and transmitted further in another form and the several transmissions may be grouped together to form a single picture.

Fig. 2 shows energy transmitted thermally from a steam boiler through a steam pipe to an engine thence mechanically through a belt to a dynamo and finally electrically to a motor.

The diminution of the stream of energy is indicated as due to separate thermal and mechanical losses of transformation in the engine, mechanical losses in the belt, combined mechanical and electrical losses of transformation in the dynamo and electrical losses in the wires.

The picture may be extended by tracing each branch forward or back to its furthest ascertainable end and it may be amplified by analyzing the losses into more elementary streams and by tracing the flow in greater detail; showing, say, the flow of energy through the reciprocating parts of the engine on its way from the steam pipe to the belt.

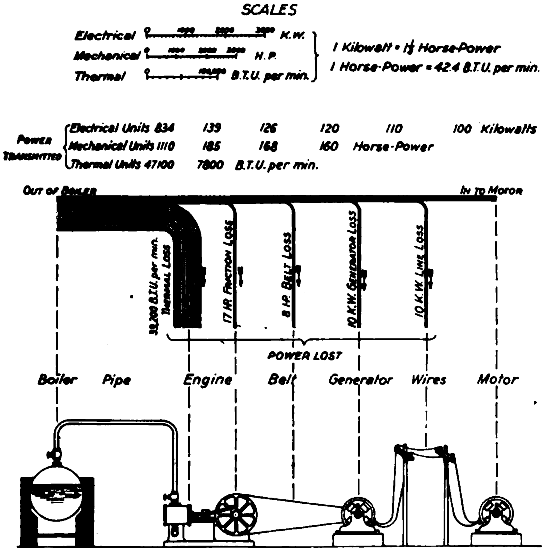
SCALES
Electrical K.W.
Mechanical H.P.
Thermal B.T.U. per min.
1 Kilowatt = 1⅓ Horse-Power
1 Horse-Power = 42.4 B.T.U. per min.
Power Transmitted
Electrical Units 834 139 126 120 110 100 Kilowatts
Mechanical Units 1110 185 168 160 Horse-Power
Thermal Units 47100 7800 B.T.U. per min.
Out of Boiler
In to Motor
39,300 B.T.U. per min. Thermal Loss
17 H.P. Friction Loss
8 H.P. Belt Loss
10 K.W. Generator Loss
10 K.W. Line Loss
POWER LOST
Boiler
Pipe
Engine
Belt
Generator
Wires
Motor

FIG. 2—THERMAL, MECHANICAL AND ELECTRICAL TRANSMISSION

While this is a general method of picturing the transmission of power it is especially useful in illustrating the meaning of terms used in electrical power transmission by alternating currents, such as wattless current, synchronous condenser and induction generator, therefore the electrical use of the method will be chosen for amplification although it will be indicated that the same things may be found in mechanical transmission.

THE DIRECT-CURRENT GENERATOR AND MOTOR

In Fig. 3 the varying widths and directions of the ribbon of energy flow show the operating characteristics of generators and motors. The width of the outgoing energy stream is of course exactly proportional to the load, but is electrical power from a generator and mechanical power from a motor. The width of the loss stream is a maximum at full load and decreases slightly down to a minimum at no load. The input stream is exactly equal to the output stream plus the loss stream; that is, the losses are necessarily drawn from the inflow, so are supplied mechanically for a generator and electrically for a motor. The main current of energy tapers down as it passes through the machine.

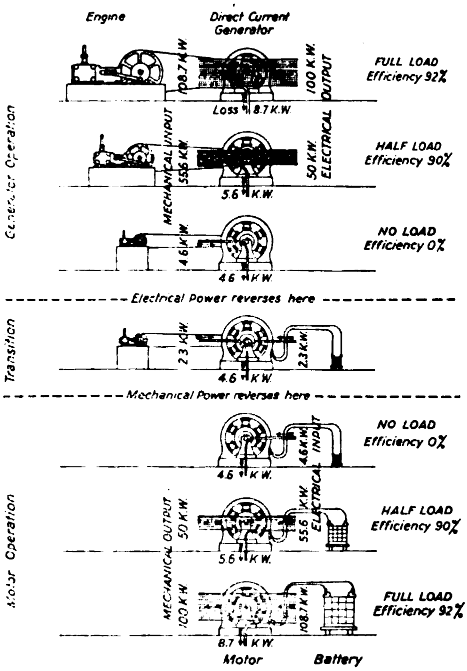

FIG. 3—DIRECT-CURRENT GENERATOR AND MOTOR OPERATION AT VARYING LOADS

The efficiency is equal to the outflow divided by the inflow. The illustration shows clearly one important point: the efficiency increases from no load to full load not because of a decrease in losses but in spite of an increase in losses.

The series of pictures may be considered as a moving picture film of the operation of a direct-current generator. It is first running in multiple with other sources of electric power and carrying full load. The operator turns the rheostat handle increasing the resistance of the field circuit and the outflow drops perhaps to half load; he turns the handle further and the outflow drops to zero, the reduced load on the engine being indicated by showing the engine as proportionally smaller. If the operator continues to turn in resistance the flow of electric power reverses. There is here a narrow transition stage where the losses, which are now at a minimum, are supplied both mechanically and electrically. When further resistance is turned in, the mechanical power also reverses and operation as a motor follows at no-load, fractional load, full load and overload in successive steps.

The series illustrates the meaning of the terms generator and motor. They describe not the construction of an electric machine but the two ways of using it. The electric machine is reversible in function. It is a generator only so long as the outflowing energy is electrical and a motor so long as it is mechanical. When it is known whether a machine is operating as a generator or as a motor two elements of the ribbon picture have been determined. First, which way the arrows of flow should point and second, as a consequence of this, which way the main flow tapers off.

TRANSMITTING MEDIUM

While a current of energy may be transmitted by using a current of water or a current of electricity the energy itself is neither water nor electrictiy. The water or electricity is but a medium of transmission. Similarly the motion which constitues the flow of the water or other mediums is not the motion which constitutes the flow of energy. The medium may be, and often is, used over and over again. The moving belt goes forward on the slack side and returns to the driving pulley on the tight side; the water goes out in the pressure pipe, leaves the engine through the exhaust pipe and may return to the pump through the suction pipe; the electricity goes out on the positive wire and returns to the generator on the negative wire. just as much belt, water or electricity comes back as goes out but the transmitted energy moves forward only. In fact the direction in which the belt, water or electricity moves can be reversed without reversing the direction in which energy is transmitted, or vice versa.

Therefore if energy is transmitted by a flow of water or of electricity a picture of the flow of energy will not be at all identical with a picture of the flow of the transmitting medium even though the same principles may be used in representing each kind of flow.

It will be understood that a representation of a flow of electrical energy is not at all a representation of a flow of electricity.

That the motion of energy and the motion of the transmitting medium are practically independent is also shown by the fact that shafts, belts, water and electricity may be in active motion and yet transmit no power and that the same mediums may transmit more power at times when they move slowly than when they move rapidly.

This is because the mediums transmit no power unless they move under pressure or tension. Power, whether mechanical or electrical, is considered as consisting of two equally important components, one of motion and one of pressure. The amount of power is the product of the two components. For hydraulic transmission the power in foot pounds per second is the product of the flow in cubic feet of water per second by the pressure in pounds per square foot and similarly, for electric transmission, the power in watts is the product of the current of electricity in amperes by the electrical pressure (potential) in volts.

Alternating Currents

Where power is transmitted mechanically by shafts, belts or fluids, or electrically by direct currents, the motion and pressure each has its own fixed direction. However, power is also transmitted both mechanically and electrically by motions and pressures which alternate in direction periodically. The pistons, piston rods, connecting rods and other reciprocating parts of a steam engine transmit mechanical power in virtue of their motion although this motion alternates in direction instead of being uniformly forward. In these cases it is important to note that the pressure as well as the motion also alternates. The pressure is on one side of the piston on the forward stroke and on the other side on the backward stroke.

Energy is the product of motion and pressure, therefore, if motion and pressure both reverse the flow of energy is not reversed, on the principle that the product of two negatives makes a positive. The reversal of the motion of the reciprocating parts of a steam engine does not reverse the motion of the energy which flows forward from steam pipe to shaft during the backward as well as forward stroke.

With uniform motion or flow the amount of energy transmitted is equal to the product of the motion by the pressure. The same formula holds for reciprocating motion and alternating flow provided it is understood that by motion and pressure is meant mean motion and mean pressure. The mean is found by squaring the instantaneous values of the quantities averaging these squares over a complete cycle and extracting the square root.

The transmission of power by electric current which alternates in the direction follows the same principle as the transmission by reciprocating mechanical motion, namely the reversal of the direction of the electric current does not reverse the flow of energy because the pressure is simultaneously reversed. An alternating current of electricity, or of water for that matter, will transmit just the same amount of power as a direct current of the same mean magnitude, at the same mean pressure, provided however, that the current and potential reverse at exactly the same time.

When the motion and pressure reverse simultaneously they are said to be in phase. Alternating motions or currents when in phase with their corresponding alternating pressures are practically equivalent to uniform motions or direct currents for the transmission of power.

Under these conditions the ribbon picture of power may be used for alternating current transmission. However, it is to be remembered that the flow represented is not the instantaneous flow, which fluctuates, but the mean flow over one or more complete cycles.

ACCELERATING POWER

It may happen that while the motion and pressure are both reciprocating or alternating, and at the same rate, they fail to reverse simultaneously.

The difference in time of reversal may be very small but it cannot be greater than a quarter of a cycle. When motion and pressure reverse a quarter of a cycle apart any further change in either direction brings the times of reversal closer together. For example, two cranks on the same shaft have their respective dead points as far apart as possible when set, like the cranks of a locomotive, a quarter of a revolution apart. Motion and pressure are then said to be in quadrature and each reverses when the other is at a maximum.

Under these conditions motion and pressure instead of being positive and negative simultaneously thereby always giving a positive product are of the same sign but half the time so that their product is half the time positive and half negative.

This change in sign of the product, that is of the power, indicates a reversal of its direction of flow. Where motion and pressure are in quadrature the energy flows forward and backward instead of moving uniformly forward. The average of the forward and backward flow is zero so that such an alternating flow of energy does not constitute a transmission of power in the ordinary sense.

The phenomena of motion and pressure in quardrature occurs wherever a mass moves with a reciprocating motion. The motion is that of the mass and the pressure that required to accelerate it. The power corresponding to their joint effect may be called accelerating power.

The power transmitted by reciprocating motion is equal to the product of the mean velocity and mean pressure when motion and pressure are in phase. The rule may be extended to apply to accelerating power.

The product of the mean velocity by the mean pressure, where motion and pressure are in quadrature, is an amount of power equal to the maximum value which the accelerating power attains during a cycle. The momentary flow at all times is proportional to this maximum. As the flow alternates in direction, giving an average value over the cycle of zero, it is convenient to use the maximum value as a measure of the flow where considering it in connection with the associated flow of energy over one or more complete cycles.

For reciprocating motion, the product of mean velocity by mean pressure is the transmitted power if the two quantities are in phase but is the accelerating power if they are in quadrature.

Accelerating power is evidently always necessary where reciprocating motion is maintained. On the whole the accelerating power neither adds to, nor substracts from, the true power transmitted. It may exist where there is no true power transmitted and for a given amount of true power the accelerating power may be greater or less. Finally it may be said that accelerating power is a peculiar form of power fundamental to reciprocating motion and that it may be considered as transmitted independently of the true power and according to its own laws.

The steam engine, containing reciprocating parts, furnishes an example of the transmission of accelerating power.

Consider a steam engine with steam shut off and running due to the momentum of the flywheel. Aside from any effects of friction or of compression in the cylinder the reciprocating parts, the piston for example, must be accelerated from the rest to a maximum velocity, then retarded (accelerated negatively) and brought to rest again in each stroke. These accelerations require forces which must be transmitted to the piston from the flywheel through the intervening parts such as the piston rod, as pressures (or tensions, which are negative pressures). The reciprocating parts are therefore transmitting accelerating pressures and at the same time are in active motion. However, it will be found that the motion of the rod reverses at the time when the pressure in it is a maximum and that the pressure reverses when the velocity is a maximum. That is, motion and pressure are in quadrature.

The flywheel is giving out power and accelerating the piston during half the time and during the other half the process is reversed. It may be said that the flywheel and the piston are interchanging accelerating power which alternates in direction.

At the instant that the reciprocating parts are passing their dead point the flywheel has a maximum velocity which is the same as though it were running freely unconnected to the reciprocating parts. At all other times the velocity of the flywheel is more or less reduced. Consequently, if reciprocating parts are connected to a flywheel previously running freely the number of revolutions per minute will thereby be reduced.

The flywheel contains a store of energy by virtue of its velocity. This reduction in the mean velocity results in a corresponding reduction in the average energy stored in the flywheel, but on the other hand the reciprocating parts acquire an equal amount of average energy due to their mean velocity.

From this point of view it may be said that the reciprocating parts have been energized at the expense of the flywheel which has been deenergized. The total stored energy of the system has not been changed but it has been redistributed.

In a steam engine, whether a simple engine with a single cylinder and crank, or a compound engine with several cranks, the motion of all the reciprocating parts, pistons, piston rods, connecting rods, valves, valve rods, and eccentric rods, is in proportion to a single angular velocity, the speed of revolution of the engine. The distribution of accelerating power in one engine may form a complex system, all however based on a single angular velocity. In this respect it is similar to an alternating-current distributing system, which however large, has a single frequency.

Where the mean angular velocity is constant the energizing of the reciprocating parts and the deenergizing of the rotating parts is directly proportional to the amount of accelerating power which flows. For example, if the weight of a reciprocating part is doubled, the energy it contains and the accelerating power it receives are both doubled while if the stroke is doubled the energy and accelerating power are each quadrupled. At constant angular velocity, the amount of accelerating power may be used as a measure of the transfer of energy, and it may be said that each reciprocating part takes a flow of accelerating power proportional to the amount to which it is energized while each rotating part is de-energized in proportion to the flow of accelerating power which it gives out.

Pictures of Accelerating Power

To make a picture of the flow of accelerating power a second ribbon may be drawn of width equal to the accelerating power, that is to the product of the mean force by the mean velocity. To distinguish between the two ribbons, that for energy transmission will be shaded longitudinally and that for accelerating power laterally.

Accelerating power may be measured in the same units as other power, that is foot pounds per second, horse power, watts or kilowatts.

Arrows have been placed on the energy flow ribbon to indicate that energy is continually passing a given point in one direction. With such a flow the total quantity of energy passed increases cumulatively with the time. The flow of accelerating power alternates in direction so that arrows to represent the successive instantaneous flows would point equally in both directions. However, in picturing the transmission of power by reciprocating motion we are not attempting to show the instantaneous values which fluctuate throughout the cycle but only the effect over one or more complete cycles.

While the accelerating power has no direction of flow it is associated with the transfer of energy from the rotating flywheel to the reciprocating piston which is in a determinate direction. As the de-energizing of the flywheel and the energizing of the piston are each proportional in magnitude to the width of the stream of accelerating power it is a useful convention to mark on this ribbon arrows to indicate the direction of the transfer of energy. It is to be remembered that this transfer is a process not cumulative with time, so that accelerating power of a constant amount may flow indefinitely from a flywheel without depleting its energy supply. The arrow on this ribbon represents a transfer of energy which occurs at the time when the flow from flywheel to piston first begins and which may be described as unstable. The transfer can only be maintained as long as the flow of accelerating power continues and in an amount proportional to the flow. Any increase or decrease of flow is accompanied by a corresponding transfer of energy.

It is further to be remembered that the direction of these arrows is determined by making the assumption that the rotating parts are the primary reservoirs of stored energy; therefore, that the flow of accelerating power (transfer of stored energy) is from the rotating parts to the reciprocating parts. This assumption is natural in the simple case used for illustration but is not essential. That is, the direction of the arrows results from a convention and could be reversed by adopting a different convention. It is of course desirable to adhere always to one convention though it is useful to know that the arrows on the ribbon of accelerating power represent but one of two possible views. The conclusions are of course the same whichever view is adopted, the language in which they are clothed being alone affected.

Fig. 4 shows the distribution of accelerating power from a flywheel to the reciprocating parts of an engine.

The speed of the engine is 150 rev. per min. The stroke of the engine is two feet giving the pistons a mean velocity of $\pi/\sqrt{2} \times 150$ rev. per min. $\times$ 2 feet or 667 feet per minute. The mean acceleration of the pistons is $\sqrt{2} \times \pi^2 \times 150^2$ rev. per min. $\div 60^2$ seconds per minute $\times$ 2 feet, or 175 feet per second per second. The high pressure pistons weighs 120 pounds and takes a mean accelerating force of 120 pounds × 175 feet per second per second divided by 32.2, or 652 pounds. The accelerating power is therefore 652 pounds × 667 feet per minute divided by 33,000, or 13 horse power.

The low-pressure piston weighs four times as much and requires 52 horse power acceleration. The valve weighs one-sixth as much and has one-fourth the travel and requires 1/96 the power, or 0.14 horse power.

The high-pressure piston is energized to an amount equal to one-half its weight multiplied by the square of its mean velocity or 1/2 × 120 pounds × 667^2 feet per minute divided by 60^2

seconds divided by 32.2 = 230 foot-pounds. The low pressure piston contains 920 foot-pounds energy and the valve 2.4 foot-pounds. These quantities of energy are exactly proportional to the accelerating power taken by the parts the ratio being 33,000 foot pounds per minute divided by 4 × π × 150 rev. per min. or 17.5. That is, a reciprocating part is energized by 17.5 foot pounds for every horse power of accelerating power which flows into it.

Magnetizing Power

What has been said of mechanical motion and pressure when in quadrature applies also to electric currents and pressures.

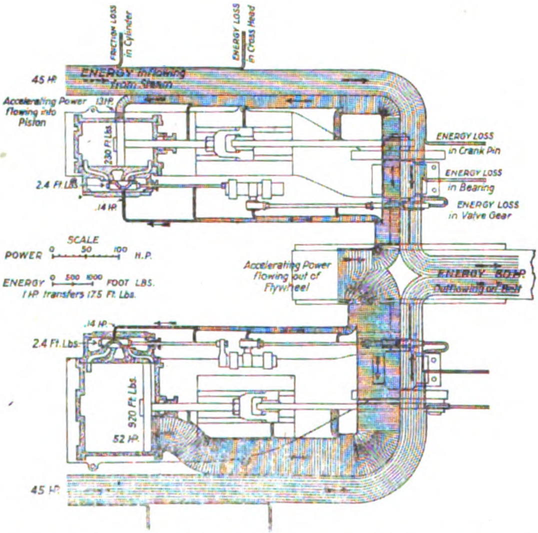
FRICTION LOSS in Cylinder
ENERGY LOSS in Cross Head
45 HP.
ENERGY inflowing from Steam
Accelerating Power flowing into Piston
13 HP.
230 Ft. Lbs.
2.4 Ft. Lbs.
.14 HP.
ENERGY LOSS in Crank Pin
ENERGY LOSS in Bearing
ENERGY LOSS in Valve Gear
SCALE
POWER 0 50 100 H.P.
ENERGY 0 500 1000 FOOT LBS.
1 HP transfers 17.5 Ft. Lbs.
Accelerating Power flowing out of Flywheel
ENERGY 80 HP. Outflowing on Belt
.14 HP.
2.4 Ft. Lbs.
920 Ft. Lbs.
52 HP.
45 HP.

Fig. 4—Flow of Energy and Accelerating Power Through Engine

As reciprocating motion necessitates acceleration of matter and that requires the application of accelerating power, so alternating electric currents necessitate the acceleration of electricity and that also requires a similar kind of power. Mechanically, the accelerating power is stored intermittently as kinetic energy in the reciprocating mass, while electrically, the power is correspondingly stored in the alternating magnetic field of the moving electricity. Wherever there is reciprocating matter there must be mechanical accelerating power and wherever there is alternating electricity there must be electric magnetizing power.

Electric currents in quadrature with the electrical pressure have been called idle or wattless currents because they transmit no power in the ordinary sense and the product of these currents by the pressure has been called wattless power for the same reason. As the power taken by reactive coils is almost wholly "wattless" the power is also called reactive power with the advantage that there is no implication that it is not really power. As the "idle" currents produce magnetization they are also called magnetizing currents and the name magnetizing power seems to give the simplest view of the function of reactive power. All of these electrical terms describe a special form of power which alternates in direction and is otherwise identical with mechanical accelerating power which exists in all reciprocating machines.

Magnetizing power it should be noted is necessary to produce magnetism alternating in direction just as accelerating power is necessary to produce reciprocating motion.

When the magnetism is uniform in direction the magnetization is produced once for all at the beginning and no further magnetizing power is required. The same distinction occurs in mechanics; uniform motion, say of a flywheel, requires accelerating power only at the time of starting, after reaching speed it will run indefinitely without further acceleration.

A permanent magnet or an electromagnet excited by direct currents may be regarded as a resorvoir of magnetism just as a uniformly moving flywheel is a reservoir of energy.

The magnets used in direct-current electrical machinery are of this type, therefore, except at the instant of starting, no magnetizing power is used.

A permanent magnet may be compared to a frictionless flywheel which will run indefinitely when once started. Flywheels in general cannot be frictionless but must have shaft and bearings. To keep such a flywheel running uniformly, energy must be continually supplied equal to the bearing friction. But it should be noted that *such energy adds in no way to the stored energy of the flywheel.* A direct-current electromagnet is similar to such a flywheel. The field current or exciting current merely overcomes electrical friction, that is resistance, and conserves the magnetization put in at the first instant.

The magnetizing power flowing into an alternating-current magnet is like the accelerating power flowing into a reciprocating piston ,while the exciting power flowing into a direct-current magnet is like the mechanical power flowing into the bearings and overcoming the friction of a flywheel.

In practically all commercial machines for interchanging mechanical and electrical power, that is, generators and motors, the mechanical forces are due to the attraction and repulsion of magnets. With alternating-current machines the magnetism of these magnets is produced in whole or in part by this magnetizing power.

An ordinary alternating-current generator also has magnets excited by direct current. These magnets serve a similar purpose to the flywheel of a reciprocating engine. As the flywheel is a reservoir of mechanical energy which is drawn on to accelerate and retard the reciprocating parts so the magnet of the alternator is a reservoir of magnetization which magnetizes and demagnetizes the alternating-current magnets of the circuit.

As we may picture mechanical accelerating power flowing out from the flywheel to each reciprocating part of an engine so may we picture magnetizing power flowing out from the generator to each motor, transformer or other part containing an alternating-current magnet.

The alternating-current magnets are magnetized at the expense of the direct-current magnets. The gain of magnetization of one exactly equals the loss of magnetization of the other.

A displacement of magnetization in a determinate direction is then associated with the flow of magnetization, which being alternating, is itself directionless. Furthermore, the frequency being the same throughout the system, the amount of magnetization displaced is proportional to the magnetizing power.

Electric machines absorb or give out mechanical energy because of attraction or repulsion of their constituent magnets. Alternating-current machinery such as ordinary generators, synchronous motors and synchronous converters contain both direct- and alternating-current magnets, while other important electric machinery such as transformers, induction motors, induction regulators and induction generators contain alternating-current magnets only.

A machine containing both direct- and alternating-current magnets may either give out or absorb magnetizing power. A machine containing alternating-current magnets only can also give out or absorb magnetizing power if provided with a suitable commutator. The use of such a commutator is however still unusual and the ordinary induction motor and most other machinery containing alternating-current magnets have no commutators. A machine containing alternating-current magnets only, and without a commutator, can absorb but cannot give out magnetizing power.

Most alternating electric machinery is designed to have an approximately constant magnetization, therefore the magnetizing power is also approximately constant. The flow of magnetization to a transformer, induction motor or other non-commutating machine containing alternating-current magnets only, can be pictured as being constant at all loads for an ideal, perfect machine. For a practical machine the flow of magnetization will increase slightly with increasing load although the useful magnetization decreases slightly, the voltage being assumed normal at all loads. Increased voltage at any load increases the flow of magnetization, and decreased voltage decreases it.

PICTURES OF THE FLOW OF MAGNETIZING POWER

Magnetizing power being but an electrical variety of accelerating power its flow may be shown by a similar picture. A ribbon may be drawn for it with a width equal to the product of the mean current by the mean potential.

Magnetizing power may be measured in the same units as accelerating or other power though in electrical work magnetizing power is measured in kilovolt-amperes instead of in kilowatts. The two units are of the same dimensions, a kilowatt being the same as a kilovolt-ampere except that its application is limited by an additional convention that the current and pressure are in phase. It may be pointed out that it is equally important to distinguish between kilovolt-amperes of magnetizing power where current and pressure are in quadrature and kilovolt-amperes of apparent power where no determinate phase relation is implied.

Arrows may be placed on the ribbon to show the direction in which magnetization has been displaced. The demagnetizing of the field magnets of an alternator and the magnetization of the fields of an induction motor being proportional to the magnetizing power, and due to its flow, there is a natural basis for describing the flow as being from the point where demagnetizing takes place and to the point where the magnetism reappears. This displacement of magnetization, like the transfer of energy from flywheel to piston, is a transient change which occurs when the flow begins but the displaced magnetization is only prevented from returning to its original state of equilibrium by the continuance of the flow of magnetizing power. The flow of magnetizing power is therefore not a cumulative flow, and if constant, does not further deplete the magnetization of the source from which it springs nor build up an indefinite amount of magnetization at its terminus.

The Induction Motor and Induction Generator

Fig. 5 shows the flow of energy through an induction motor at varying loads. As previously mentioned, an induction

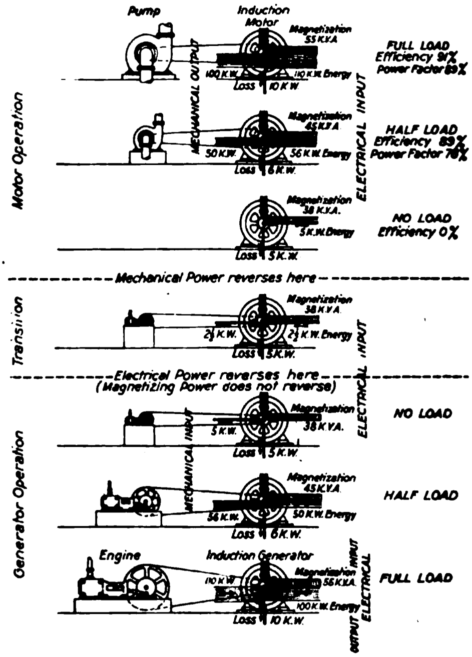

Fig. 5—Induction Motor and Induction Generator Operation at Varying Loads

motor contains alternating-current magnets only and, therefore, must receive magnetizing power from some external source. The motor receives from the generator two independent kinds of power. The ordinary flow of energy through it is similar to that through a direct-current motor and requires no further comment.

The magnetizing power which flows into the motor and goes no further is the peculiar feature. The width of this power ribbon does not vary much from full load to no-load. Motors of different sizes take magnetizing power approximately in proportion to their horse power rating; though small motors take a somewhat greater proportion due to less perfect design. Slow-speed motors take more than high-speed motors of the same rating, because the speed being low, the maximum torque must be high, and as the diameter of the armature is not increased sufficiently to maintain the same surface speed, a high torque requires more magnetic attraction and consequently more magnetism. Subject to considerable variation due to such causes, the figures shown may be taken as typical of any induction motor.

An induction motor like other motors is reversible in its function and may operate as a generator and is then called an induction generator.

Fig. 5 is extended to show the transition from motor to generator action. The operation of the motor as a generator amounts to a reversal of the flow of energy, precisely as with a direct current machine.

However, *the flow of magnetizing power does not and cannot reverse.* An induction generator cannot produce magnetizing power. The induction motor is a reversible machine as regards the flow of energy but not as regards the flow of magnetization. This explains why one induction motor operated as a generator cannot operate another as a motor unless some other machine is also connected which is capable of furnishing the magnetizing power for both machines. It also shows why it may be advantageous to forego the simplicity of the ordinary induction motor and add a commutator so that the inward flow of magnetization may be reduced, eliminated or reversed.

SYNCHRONOUS MOTOR AND ALTERNATING-CURRENT GENERATOR

An alternating-current generator can operate as an alternating-current motor and is then called a synchronous motor. The synchronous motor differs from the induction motor in being completely reversible, that is reversible as regards the flow of magnetization as well as of energy. Where an alternator transmits power to a synchronous motor there are three cases as shown in Fig. 6.

The simplest case is where, as in direct-current transmission, no magnetizing power is required. Each machine has its magnetization furnished locally by direct currents. The equality of excitation is indicated in the figure by drawing the exciters of the generator and motor as of the same size.

Above this case is shown the one where magnetization as well as energy is being transmitted from the generator to the motor. This indicates that the motor has insufficient magnetization, it is therefore, said to be under-excited. The less the direct-current excitation of the motor, the greater the magnetizing power absorbed by it. This magnetizing power produces a useful magnetization in the motor just sufficient to supplement the inadequate direct-current magnetizaton. If the direct-current excitation decreases, the magnetizing power increases, so that finally, if the direct-current magnetization fails entirely, the magnetizing power alone may furnish approximately normal magnetization. A synchronous motor may, therefore, run without direct-current field excitation, in fact, this principle is used in starting synchronous motors and converters. Such an unexcited motor is similar to an induction motor but is so imperfectly designed for unexcited operation that it takes a much greater proportion of magnetizing power.

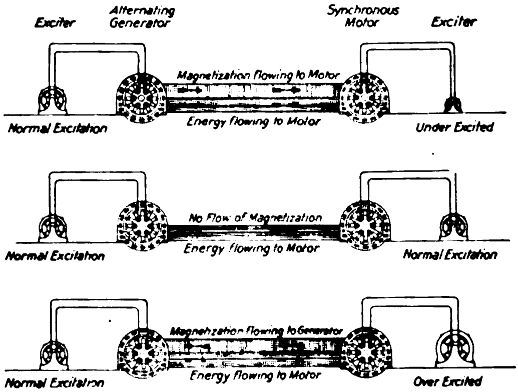

FIG. 6—FLOW OF ENERGY AND MAGNETIZATION AT VARYING EXCITATIONS

An unexcited synchronous motor is, like an induction motor, reversible in regard to flow of energy and may be used as a generator. However, an unexcited generator or motor must absorb and cannot produce magnetizing power. Therefore, an unexcited generator cannot be used to run an unexcited motor unless there is some other source of magnetizing power adequate for both generator and motor.

At the bottom of the figure is shown the case where the motor has an excessive amount of magnetization or is over-excited. The magnetizing power now flows from the motor to the generator. The effect of this flow is to demagnetize the motor, the amount of flow being just sufficient to bring the magnetization of the motor down to equality with that of the generator.

The principle is, in fact, general, that magnetizing power demagnetizes the machine from which it proceeds and magnetizes the one into which it flows. Magnetizing power may, therefore, be imagined as a current or flow of magnetization from points of surplus to those of deficient magnetization. The surplus magnetization is to be found in those machines strongly excited by direct currents, the deficient magnetization in those weakly excited and more especially in transformers, induction motors and other apparatus having no direct-current excitation at all. Strong and weak excitation are of course only relative terms. If the excitation of a generator and a motor are equally strong or equally weak no flow of magnetizing power between them is necessary to preserve a balance. The voltage which a machine tends to have, due to its direct-current excitation alone, furnishes perhaps the simplest measure of the strength of excitation from the present point of view.

Where several alternating-current machines having direct-current excitation are connected together, the increase in the excitation of any one machine tends to raise its voltage but this tendency is counteracted by a magnetizing current which flows away from it to the other machines, demagnetizing it and magnetizing them. A considerable increase in excitation of one machine, therefore, produces a smaller though widespread increase in magnetization of all the machines. Conversely, a decrease in excitation of one machine causes an inflow of magnetizing power and a corresponding reduction in the voltage of the whole system. This condition holds whether the machines are all alternators or all synchronous motors or a mixture of the two. The function of the machine, whether generator or motor is immaterial, the relative excitation is the essential thing.

The relative excitation of the machines (generators and motors) on a system governs the flow of magnetization and of that alone. The origin of the excitation is immaterial as regards the flow of energy; the excitation may all come from one machine, any one, or from all the machines in any proportion. As long as some source of adequate magnetization is provided the several machines may be driven as generators or operated as motors at will.

Consequently increasing the excitation of one of two alternators will not shift load to the other and an alternator may continue to carry its full load even if its excitation is lost.

Raising the voltage at one power house will not shift load to another and the voltage may be higher at the delivery end than at the generating end of a transmission line.

It is true that such increasing of excitation and raising of voltage does shift the flow of power but it is the flow of magnetizing power only, not the flow of energy.

In every alternating-current system two kinds of power coexist and flow independently. The two kinds may flow in the same or in opposite directions. Either flow may vary without interfering with the other flow.

We may picture the variations in the two ribbons of power from a generator. The operator can with his right hand increase decrease, stop or reverse the flow of the ribbon of energy by opening and closing the engine throttle or governor controller while with the left hand he may similarly and independently control the ribbon of magnetization by raising or lowering the excitation by the field rheostat. The governor controller and the rheostat are the two handles by which to take hold of the two flows.

THE SYNCHRONOUS CONDENSER

Fig. 7 shows first an alternating-current generator at full load and over-excited. As the load is reduced, the energy flow decreases, stops and reverses just as previously shown for a direct-current machine. As the excitation is supposed to remain unaltered the outflow of magnetizing power is practically unaffected by these changes of load by which a generator has become a motor. The transition stage between motor and generator operation presents the peculiarity that the machine though neither a motor nor a generator still produces magnetizing power. This feature is of such importance that the machine when so operating has a special name, being called a synchronous condenser.

The synchronous condenser can be used to produce the magnetizing power required for operation of induction motors or induction generators or for the starting of unexcited synchronous motors or in fact for producing all or any part of the flow of magnetization required for a transmission system.

The amount of magnetization produced is under control, depending on the amount of excitation. The figure shows that with decreased excitation the flow of magnetizing power eventually ceases and that a further decrease reverses the flow. An under-excited synchronous " condenser " may be called a synchronous reactor.

TRANSFORMERS

Power consists of the product of two components, velocity and pressure. Either may be increased at the expense of the other and the power remains the same.

Mechanically, increase of pressure with decrease of velocity may be accomplished by gearing. In this graphical representation of power where the power as a whole is shown but not its components the transmission of power through gearing makes no change in the direction of its flow nor in the width of the stream except for the diversion of a small amount corresponding to the losses in the gearing.

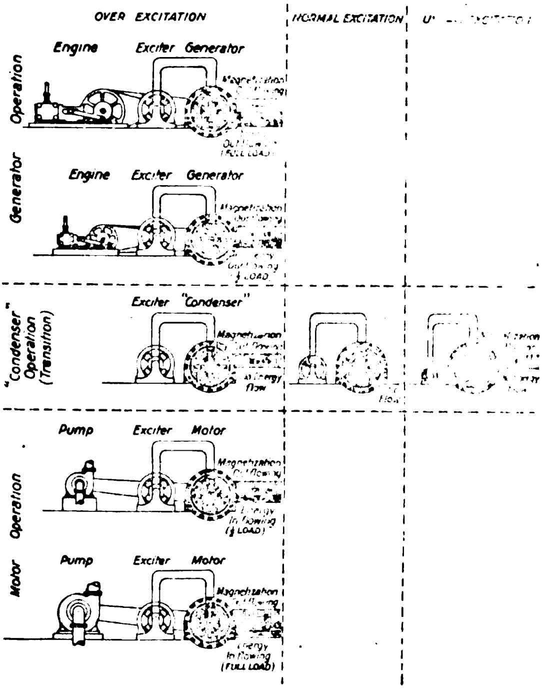

FIG. 7—SYNCHRONOUS CONDENSER OPERATION

Transformers are used for increasing electrical pressures with corresponding decrease in current. A transformer is therefore a kind of electrical gearing and power will pass through it with no change except a slight diminution to cover transformer losses.

Accelerating power can be geared up or down mechanically just as well as energy flow. Similarly magnetizing power can be transformed as readily as energy flow. A transformer is therefore no barrier to the free and independent flow of the two kinds of power.

The electric transformers are a type of gearing corresponding mechanically to a direct-acting pump; the change of pressure being produced by alternating or reciprocating motion. The transformer, therefore, must itself receive a small amount of magnetizing power in order to work at all, but this is an approximately fixed amount and does not otherwise affect the free flow of magnetizing power through it.

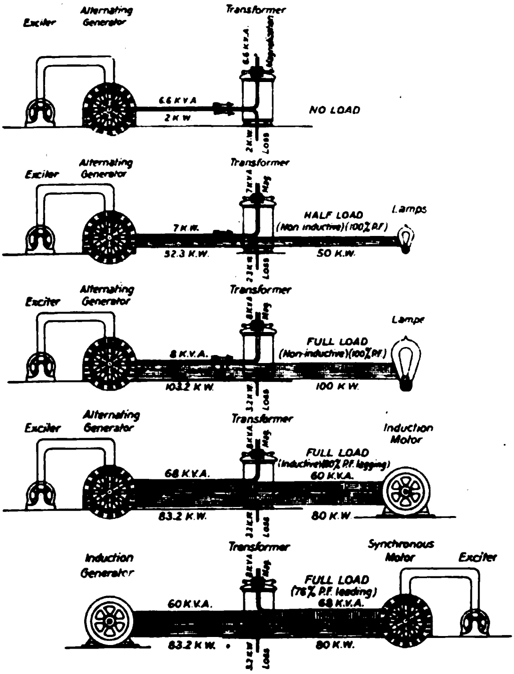

FIG. 8—FLOW OF ENERGY AND MAGNETIZATION THROUGH A TRANSFORMER

The magnetizing power taken by a transformer is similar in characteristics to that of an induction motor. The principal difference being that the magnetic design of a transformer is much more perfect than that of an induction motor so that the proportion of magnetizing power taken is much smaller.

Fig. 8 shows the flow of power through a transformer. The transformer diverts from the energy stream a small branch which is consumed as transformer loss and from the magnetizing stream another small branch which magnetizes the core. Even at no load the transformer must receive these two small streams if it is active. Ordinarily both streams come from the same direction, that is from the generator but this is not essential for when an induction generator drives a synchronous motor through the transformer the energy loss stream comes from the generator, the magnetization stream from the motor.

In a broad way generators and motors as well as transformers may be considered as a kind of gearing.

A generator, like a transformer or a gear, transforms the product of one motion and one pressure into an approximately equal product consisting of a different motion and a correspondingly different pressure.

Where both motions and pressures are mechanical the transforming device is called gearing, where one pair is mechanical and the other electrical it is called a motor or generator, and if both are electrical it is called a transformer.

APPARENT POWER

While energy flow and magnetizing flow can be considered to exist in the same circuit practically independently, there are not two distinguishable currents of electricity in the same wire. The currents and pressure of energy flow and of magnetizing flow combine into a single current and pressure. Neither the current nor the pressure alone show any trace of the two components of which either may be considered to be built up. However, on comparing the composite current with the composite pressure it is found that the times of reversal are no longer either simultaneous nor in quadrature. The effect on current and pressure of combining energy and magnetizing flow is to shift the relative time of reversal, or as it is ordinarily expressed, the phase is shifted. Conversely, it is found that whatever the difference in phase, the total effect of the current and pressure can be analyzed into two parts, one giving energy flow only and the other magnetizing flow only and this forms one basis of the conclusion that energy flow and magnetizing flow are two fundamental kinds of power.

The product of current and pressure is power, the kind of power depending upon the phase. Disregarding the phase, which is often unknown, the product is called apparent power. When the phase of the two quantities is the same the apparent power is the same as energy flow, when phases are in quadrature it is the same as magnetizing flow. For intermediate phases apparent power consists of an energy flow component and a magnetizing flow component. It is found that the square of the apparent power is equal to the sum of the squares of the energy flow and the magnetizing flow.

This leads to the conclusion that if the ribbons representing energy flow are laid say horizontally and those representing magnetizing flow are turned vertically then a diagonal ribbon connecting them will represent the apparent power.

Fig. 9 shows how a flow of 80 kilowatts of energy and 60 kilovolt-amperes of magnetization give an apparent flow of 100 kilovolt-amperes.

While apparent power is not itself a fundamental kind of power it is perhaps more readily measured than either energy flow or magnetizing flow, as it is only necessary to measure the current by an ammeter and the pressure by a voltmeter and multiply the result, without regard to the difference in phase.

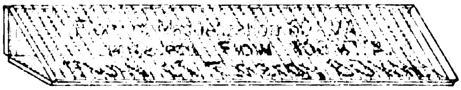

FIG. 9—APPARENT FLOW RESULTING FROM FLOWS OF ENERGY AND MAGNETIZATION

It is also of importance because furnishing a measure of the size of generators, transformers, motors, etc., which must be used to transmit simultaneously the flow of energy and of magnetization.

POWER FACTOR

Power factor expresses the relation between energy flow and apparent power. It is the number of kilowatts of power delivered per kilovolt-ampere apparently transmitted.

When the power factor is fixed the relation between the magnetizing and energy flows is also fixed. If the power factor is constant the magnetizing and energy flows can only increase or decrease proportionally.

Fig. 10 shows the relation between the flow of energy and the flow of magnetization at various power factors. The two flows are equal for a power factor of $1/\sqrt{2} = 71$ per cent. With increasing power factors the proportion of magnetizing flow diminishes until it vanishes at unity power factor while with decreasing power factors the proportion of energy flow diminishes and it becomes zero at zero power factor.

While the magnetizing power is relatively less at low than at high power factors an increase in power factor does not necessarily mean that the magnetizing power has decreased. Thus, in an induction motor, the power factor is higher at full load than at no-load, nevertheless the magnetizing power is also greater. The increased power factor results from a great increase in energy flow accompanied by a small increase in magnetizing power.

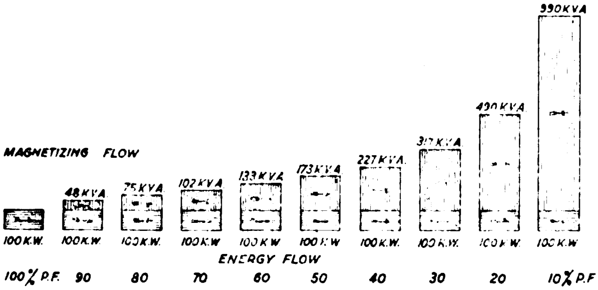

FIG. 10—RATIO OF MAGNETIZING FLOW TO ENERGY FLOW AT DIFFERENT POWER FACTORS

LAGGING AND LEADING CURRENTS

The terms lagging and leading indicate the relative directions of flow of the two kinds of power. If they flow in the same direction the current is said to be lagging, if in opposite directions, leading. If the current is lagging it may be changed to leading by reversing either but not both of the flows. If a synchronous motor is under-excited the current is lagging. Increasing the excitation makes the current leading because it reverses the flow of magnetization while the flow of energy is not affected. If however the excitation is not increased but mechanical power is applied to drive the motor as a generator, the current also becomes leading because the flow of energy has been reversed while the flow of magnetization is not changed. If the excitation is increased and mechanical driving power is also applied, the current remains lagging because both flows have been reversed. These effects are shown in Fig. 11.

BRANCHED CIRCUITS

Where a circuit branches, say from one generator to two motors operating at different power factors, the determination of the power factor of the generator from that of the motors looks rather complicated The same problem is extremely simple if viewed as the division of two kinds of currents each into two branches.

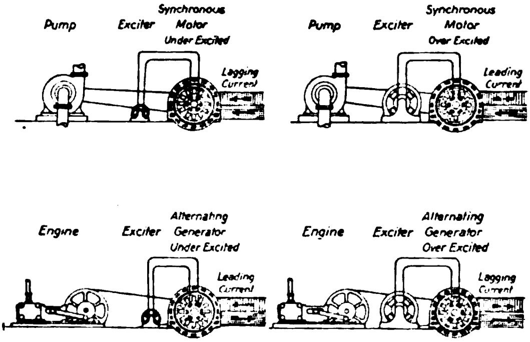
Pump
Exciter
Synchronous Motor Under Excited
Lagging Current
Pump
Exciter
Synchronous Motor Over Excited
Leading Current
Engine
Exciter
Alternating Generator Under Excited
Leading Current
Engine
Exciter
Alternating Generator Over Excited
Lagging Current

FIG. 11—DIRECTIONS OF FLOWS WITH LEADING AND LAGGING CURRENTS

For example a generator supplies an induction motor taking 80 kilowatts at 80 per cent power factor lagging, and a synchronous motor taking 100 kilowatts at 98 per cent power factor leading. It is evident that the generator supplies the sum of 80 and 100 kilowatts, or 180 kilowatts but it is not very obvious that its power factor is 97.6 per cent lagging.

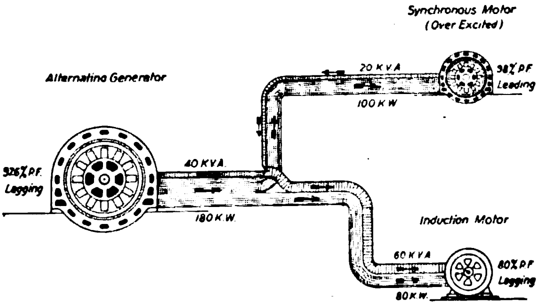

FIG. 12—POWER FACTORS OF A BRANCHED CIRCUIT

Fig. 12 shows that this complicated relation of power factors is merely a roundabout way of saying that the induction motor takes 60 kilovolt-amperes of magnetizing power while the synchronous motor gives out 20 kilovolt-amperes, therefore, the generator must give out the difference, or 40 kilovolt-amperes.

From these elements a picture may be drawn of the flows of energy and magnetization in any transmission and distribution system. The ribbons show graphically the equality between inflowing and outflowing energy and between inflowing and outflowing magnetization. A single flow of energy may have associated with it two or more separate flows of magnetization as shown in Fig. 13. Here a synchronous condenser forms a local source of magnetization for the induction motors at the end of a transmission line, thus saving the losses of transforming and transmitting this flow as well as performing other useful functions. The generator is shown as furnishing the magnetizing power for motors in its vicinity. Water power transmission systems usually have little load at the generating end and there are indications that a normal method of operation of such systems is to have the source of magnetization at the receiving end. When the flow of magnetization is in the opposite direction to the flow of energy at full load, the voltage drop due to the load is decreased, and the regulation is improved.

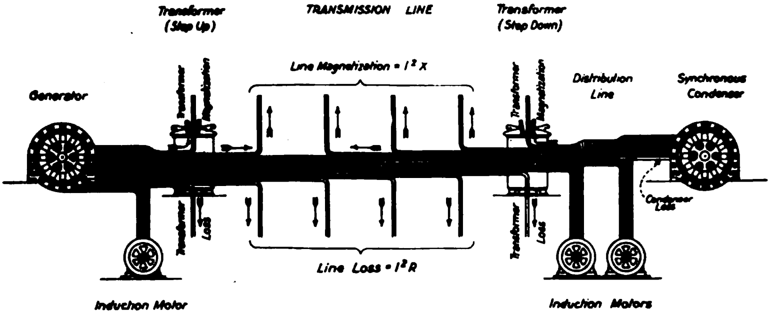

FIG. 13—FLOW OF ENERGY AND MAGNETIZATION THROUGH TRANSMISSION LINE

CHARGING POWER

The electric phenomena previously described are those which result from the storage of energy in an electric circuit due to magnetization. Energy may, however, also be stored in another form due to electric charging. Where the electricity is used in the form of alternating currents the electric charging current, like the mangetizing current, must transport this energy to the part charged and back to the source periodically. Charging power must flow to every part where there is electrostatic capacity. With charging power as with magnetizing power the current and potential are in quadrature. In fact charging power is the same as magnetizing power except that the direction of flow is reversed. That is, a kilovolt-ampere of charging power flowing south is the same as a kilovolt-ampere of magnetizing power flowing north. The single term, magnetizing power, is then sufficient for both. The choice of the term magnetizing power instead of charging power furnishes the basis of the convention which has been used in indicating the direction of flow of this kind of accelerating power.

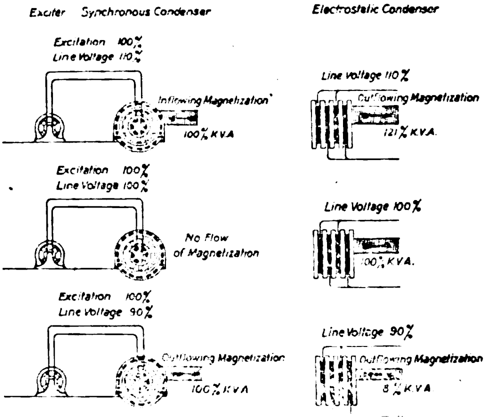

FIG. 14—FLOW OF MAGNETIZATION AT VARIOUS LINE VOLTAGES

However, this difference should be noted—an alternating-current electric condenser is always a source of magnetizing power while an alternating-current magnet is always a sink in which such power disappears.

The alternating-current condenser and the alternating-current magnet are complementary.

The electric condenser, therefore, may be used as a substitute for the direct-current magnets of an alternator in furnishing the magnetization of a transmission system.

An alternator without direct-current field excitation may receive all needed excitation from an electric condenser, and an induction motor may operate as an induction generator receiving its magnetization from a condenser. These results are obtained in practise, though they are not the normal operating conditions on high-tension transmission systems.

A rotating machine structurally identical with an alternator or synchronous motor, but not performing any mechanical work, may furnish the magnetizing power for a system, in whole or in part, much as an electrostatic condenser would, and hence is called a synchronous condenser.

Fig. 14 shows the essentially different behavior of an electrostatic condenser and a synchronous condenser as the voltage changes. The flow of magnetizing power from an electrostatic condenser increases as the square of the voltage. Magnetizing power flows from a synchronous condenser only when the circuit voltage is below that corresponding to the excitation of the condenser. If these voltages are equal the synchronous condenser is neutral as regards magnetizing power. If the circuit voltage is higher, the synchronous condenser absorbs magnetizing power and ceases to be like a condenser, becoming similar to a reactor.

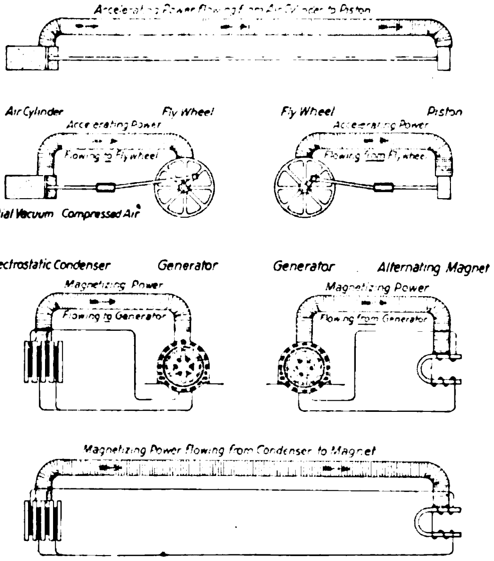

FIG. 15—FLOW OF ACCELERATING POWER AND MAGNETIZING POWER IN OSCILLATING CIRCUITS

The phenomena due to charging power are not peculiar to electrical transmission. If the steam ports of an engine are permanently closed when the piston is in mid position in the cylinder it cannot be moved in either direction without compressing the air on one side and expanding that on the other side. If the engine shaft is rotated the piston will require a reciprocating force to overcome the air pressure and this force will be zero at midstroke and maximum at the dead point; that is, it is in quadrature with the motion. For a given direction of motion the direction of this force will be opposite to that which would be required for acceleration. This reversal of one component but not of both, reverses the direction of the power. Consequently, such an air-cushioned piston becomes a source of accelerating power. As it passes the dead point the flywheel now has its minimum instead of its maximum velocity. The effect of connecting the air cylinder to the wheel at this point is to energize it.

Fig. 15 shows that the outflow of accelerating power from an air cylinder is like the outflow of magnetizing power from an electrostatic condenser, one energizes the flywheel, the other magnetizes the generator. Conversely the reciprocating piston and the alternating magnet each take a corresponding inflow and de-energize the flywheel and de-energize the generator, respectively.

If the two flywheels are combined, the energizing and de-energizing processes may cancel. The flywheel then becomes unnecessary to maintain the motion and consequent flow of accelerating power and the reciprocating motion of the piston may be maintained by connecting it directly to the air cylinder. It is then merely a weight oscillating at the end of an air spring.

The two generators may be similarly combined and eliminated, giving an electrical oscillating circuit of a magnet and a condenser.

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CLASS RATES FOR LIGHT AND POWER SYSTEMS OR TERRITORIES

BY FRANK G. BAUM

ABSTRACT OF PAPER

The author offers arguments in support of the principle of establishing uniform rates throughout a system or territory for different classes of service. In establishing the rates he segregates the services into eight different classes and divides the rates into energy and demand charges; the energy charges being those charges which increase with the kilowatt-hours supply and the demand charges being proportional to the peak demands of the different classes.

By establishing similar rates for similar services throughout a territory any appearance of discrimination is avoided and a sliding scale of rates will take care of quantity consumption.

IN analyzing the load of a large system into classes we try to determine the relative facilities demanded by the different classes as a whole. In doing this we try to consider all the classes of the system as though each class were supplied as a whole from a common substation busbar through one kilowatt-hour meter and one demand meter, for each class as shown on Fig. 1, which is presumed to be the condition for the loads of the six classes shown in Fig. 2.

ANALYSIS INTO CLASSES

An examination of the load curve of a power system and a comparison of this curve with the load curves of the different substations shows at once that there is often no relation between the system load curve and the substation load curve. The reason is, of course, because the system load curve reflects at each time of day the characteristic demands of the system as a whole, while the local load curve measures only the characteristic of the particular town or industries being supplied by the substation. The two characteristics may be quite different.

If, however, instead of comparing the load at each substation with the system load curve, we analyze the system and the local load curves into "classes of service," we see at once an interesting and definite relation between the load curves of

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certain classes of business in all districts. See Fig. 4 for class 1 and 2 demands in cities of different size. In the power classes the same general similarity is noted for a given class of consumers.

The characteristic loads on a large system may be segregated into several large classes; and if these classes of service are then present in any given town or supplied from any given substation it will be at once apparent. In Fig. 2 is given a characteristic "system" load curve and on the same figure is shown the load curve of certain classes of business. The principal classes of business on the system may be divided as follows:

Class 1. Residence and peak lighting. This load comes on the system, reaches peak and drops off again in all towns and cities at about the same time. This class of service extends over about six hours per day and the load curve is quite definite in character and practically the same over the entire system. The peak of the load curve (marked Class 1) covering about six hours shows this service. This service almost always determines not only the maximum peak load, but the time at which the peak occurs. The load factor can be predicted between 15 and 20 per cent.

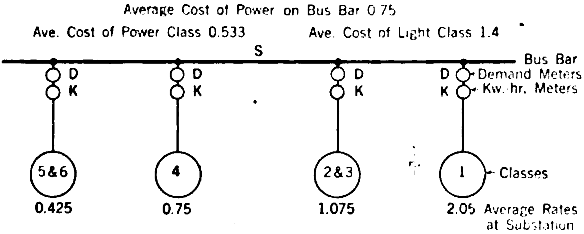
Average Cost of Power on Bus Bar 0 75
Ave. Cost of Power Class 0.533
Ave. Cost of Light Class 1.4
S
Bus Bar
D
K
D
K
D
K
D
K
Demand Meters
Kw. hr. Meters
5&6
4
2&3
1
Classes
0.425
0.75
1.075
2.05
Average Rates at Substation

FIG. 1—ANALYSIS OF LOADS INTO CLASSES AT COMMON SUBSTATION. RATES SHOWN FOR CONDITIONS AS PER FIG. 2

Class 2. Commercial lighting and small power. If the system load curve is broken up into two curves, one representing the power and the other the lighting (marked lighting and power in figure), and if, then, from the lighting curve we take the residence and street lighting, the remainder may be called the commercial lighting. It will include day lighting and small motors on the lighting circuits, electric irons, cookers, etc. This curve (class 2) is also fairly definite for different towns.

Class 3. Street lighting. This load has also a definite characteristic with modern installations and is quite uniform in different towns. This load can easily be measured directly

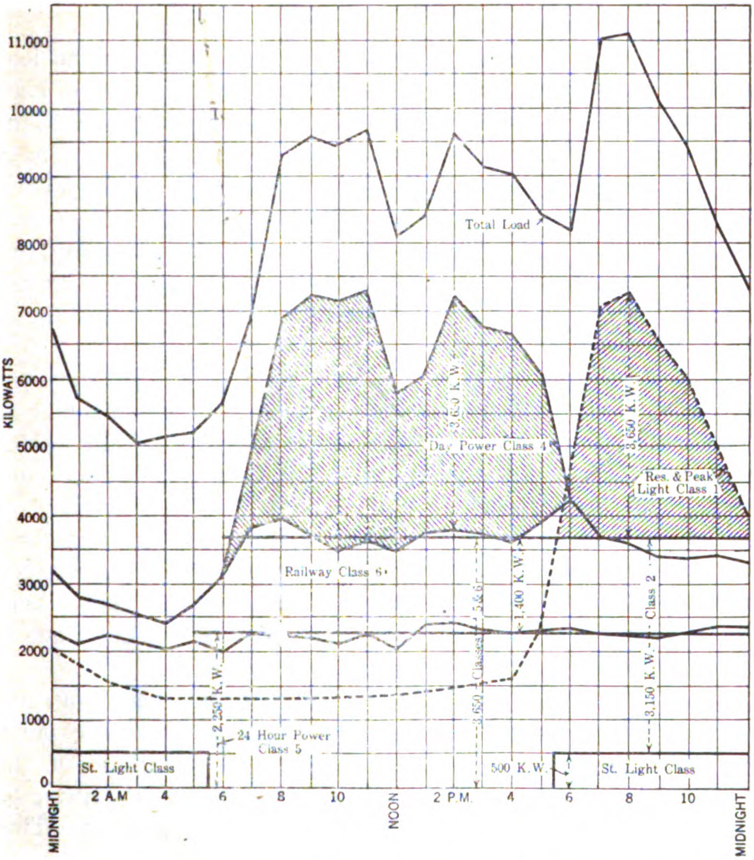

FIG. 2—CLASS LOAD CURVES AND RATES FOR POWER FOR DIFFERENT CLASSES AT SUBSTATIONS

Total to be earned inc. substation	$450,000
Energy charge for fuel and storage water at 0.1c	60,000
Total fixed charge	$390,000

This charge equally divided per proportion maximum demand as follows:

Class	Peak	Fixed charge	Million kw-hr.	c. F.C.	Total c. kw-hr.
1	3650	$ 97,500	5	1.95	2.05
2 & 3	3650	97,500	10	0.975	1.075
Total lt. class	7300	195,000	15	Av. Lt. 1.3	Av. Lt. 1.4
4	3650	97,500	15	0.65	0.75
5 & 6	3650	97,500	30	0.325	0.425
Total pr. class	7300	195,000	45	0.433	Av. Lt. 0.533
Total all classes		$390,000	60	0.65	Av. all 0.75

Note: Rates are for power to secondaries of substation transformers. Segregation may be carried on same principle to any particular sub-class in the above main classes.

Note: The figures assumed for kw-hr. are taken to make problem simple for illustration. Load factors for Classes 5 and 6 are 20 to 30 per cent higher than usually obtainable and hence rates for these classes are 20 to 30 per cent low compared to other classes.

and gives almost a constant load from dark to daylight. Class 3 is shown on bottom of figure.

Class 4. Day power. The system load curve, or the load curve of the power load, shows a very definite increase in load, starting about 6 a. m. and rising to a maximum about 10 a. m., dropping between 12 noon and 1 p. m., rising again to a maximum in the afternoon and dropping off about 6 p. m. This is the industrial power representing the motor loads in factories, machine shops, etc. The load is quite definite each day (excepting Sunday) and is as characteristic as the evening lighting peak. This load is shown by class 4 in the figure; load factor 30 to 40 per cent.

Class 5. Day and night power. This load represents the service to cement plants, dredgers, mines, etc., and includes all those users for which the load is quite constant. This load is shown by class 5 on the figure. The load factor may vary from 60 to 80 per cent.

Class 6. Railway power. This load curve is quite uniform for a general street railway system and can be determined easily, as usually the load is large and separate records are kept for this service. The load curve is shown and marked Class 6. The load factor is usually about 55 per cent.

Class 7. Irrigation. This load depends on the lack of rainfall and on the season of the year. And as these are fairly uniform over a large area, the load is characteristic of the season. This load covers usually the time from late spring to early fall and hence differs from the above six classes. This load, being generally on rural circuits, can be quite definitely determined. This load is generally required off peak. This load is seasonal and not shown on the figure.

Class 8. Reclamation. This load depends largely on rainfall, instead of the lack of it, as in the irrigation service, and hence this load partially, but not entirely, comes before the irrigation season. This load, like the irrigation load, is generally on rural circuits and can be quite definitely determined. This load is generally required to remain "off peak." This load is seasonal and is not shown in the figure.

Now let us go back to the total load curve and assume we have determined the load curve of the last two classes (that is irrigation and reclamation) and subtracted the same, for any given time, from the total load curve of the system, we then have a load curve such as shown by the heavy line in Fig. 2 representing the total load of the first six classes.

Now break this load curve into two curves, one representing the load of the classes 1, 2 and 3, residence, street and commercial lighting, and the others representing the load of the classes 4, 5 and 6, industrial, railway and 24-hour power. This gives us the curves shown on Fig. 2 as light and power with the six classes shown. These curves are quite characteristic and very important relations are shown by these curves. We see at once we have an evening lighting peak in the lighting class and a day peak in the power class. General characteristics of the classes may be tabulated as follows:

Class	Time	Peak	Class load factor	
1. Residence and peak lighting	daily	7 p.m. to 8 p.m.	15 to 20%	Lighting class
2. Commercial lighting.....	daily	6 p.m. to 10 p.m.	30 to 50%	20 to 35%
3. Street lighting	daily	6 p.m. to 12 p.m.	30 to 50%	
4. Day power....	work days	10 a.m. to 2 p.m.	30 to 40%	Power class
5. Day and night power......	daily	8 a.m. to 6 p.m.	60 to 80%	45 to 70%
6. Railway power	daily	7 a.m. & 6 p.m.	50 to 55%	
7. Irrigation power........	seasonal	10 a.m. & 2 p.m.	10 to 15%	
8. Reclamation power.....	seasonal	6 a.m. to 6 p.m.	10 to 15%	

NOTE:—Overhead and underground service in some of these classes.

(Relative rates for service at substation for different classes shown in Fig. 2 and in Fig. 3 for varying energy charge.)

Rates for classes 7 and 8 are more difficult to determine because the season largely determines earnings. These are special classes and not present on every system.

Now let us suppose we wish to find the equitable rates to be charged these various classes. We will assume that the total charge against all classes is determined and is found to be $450,000.00. This amount may be derived for illustration as follows: Assume this is a water power plant of 15,000 kw. installed capacity, and that it costs without steam reserve $2,500,000 including transmission and substation. The annual charges against the system may be made up as follows:

Interest..................	8 %...........	$200,000.00
Depreciation.............	1.5%...........	
Maintenance.............	1.5%...........	
Taxes and insurance......	1 %...........	100,000.00
	12 %	$300,000.00
Operation, repairs and management........		150,000.00
		$450,000.00

This gives the total amount to be earned by all classes and it is desired to equitably proportion these charges to the six classes shown in Figs. 1 and 2. In order to simplify the problem, we have combined classes 5 and 6 and classes 2 and 3 in the calculations in Fig. 2, and will assume that the lighting class has a total demand of 7,300 kw., and this is divided equally between class 1 and classes 2 and 3. Similarly the power class has a peak demand of 7,300 kw. and this is again equally divided between class 4 and classes 5 and 6 combined. The kilowatt-hours consumed by each class is shown in Fig. 2 and the demand and time of demand of each class is also shown.

Before we can proceed to find the rates to be charged the different classes we must determine what is the demand and what is the energy charge.

ENERGY AND DEMAND CHARGES

It is believed business will develop most naturally if energy and demand charges are divided as nearly possible in response to natural normal costs, and that the business of the various classes will develop most naturally if each class is made to bear its fair share of costs, having due regard for the fact that as a matter of policy it should be remembered that the low class power business promotes industrial and agricultural activity and tends to build up a stable and prosperous community, and hence also increases the lighting business indirectly.

Energy charges should only include those items that increase the cost to the company as kilowatt-hours are increased. Clearly for a water-power plant depending on the natural flow of the stream, all charges are fixed and are demand charges. For a steam plant energy charges are those charges that go to purchase fuel and water for the steam plant. For a water-power plant with steam reserve, or its equivalent storage water, the cost of the fuel for the steam reserve plant and the cost of the storage water are energy charges. All other charges are demand charges.

We have then the two important factors to determine rates.

(1) Energy charges are those charges that increase with the kilowatt-hours supplied to the system; that is, fuel cost for steam reserve plant and storage water cost for water-power plant.

(2) Demand charges are all other charges to substation; that is, demand charges are all charges necessary to bring the system up to frequency and voltage and include all interest, de-

preciation, maintenance and all operating expenses occasioned by demand.

It is seen then that energy charges are merely those charges that are necessary to *maintain* frequency and voltage to give service after the no-load and demand charges are accounted for to demand charges.

Energy charges will vary therefore from zero for the water-power plant without storage cost, to the fuel cost of the energy produced by a steam plant. The items to be charged to energy are so simple that there can be no controversy as to what should be charged to energy and what should be charged to demand in any given case.

For the example shown in Fig. 2 it is assumed that the company has invested money in water storage to carry the load through the short water period. It may have invested say $500,000 for this storage and this must earn 12 per cent or $60,000 per year. Now this storage water is used by the different classes in proportion to the kilowatt-hours of the classes and should be so charged. All classes use 60,000,000 kw-hr. so we have an energy charge of 0.1 cent per kw-hr. to each class. Subtracting this $60,000 from the $450,000, the total amount to be earned, we have $390,000 demand charges.

Now this $390,000 should be divided proportionately to demand (see Fig. 4) among the classes. The best way to see that this is correct is to assume that one or more of the classes is not on the system and see what relative part of this demand cost remains. Suppose we have no power consumers, then the peak load of the system will be 7300 kw., the same as the lighting peak, instead of 11,000 kw., the total peak when both classes of consumers are on the system. We could therefore have a station with a peak plant capacity of 10,000 kw. instead of 15,000 kw. actual when both power and light consumers are on the system. That is, we would have a saving in plant investment if we were serving only light. Now assume we have no light consumers and you at once see that the results as to plant capacity is the same. In other words the same investment and operating expenses, except storage water, would be required for the power consumers as for the lighting consumers.

Instead of each class supporting a station capacity of 10,000 kw., the two classes when combined on one system only need support a station capacity of 15,000 kw. This is due to the diversity factor, that is, to the difference of time of peak of the two classes and shows the advantage to consumers of developing both classes of business. This was illustrated in a number of ways in my previous paper on "The Best Control of Public Utilities," see Jan. 1915 PROCEEDINGS. The equity of charging the power consumers and lighting consumers in proportion to peak demand is shown above and can be shown in a number of other ways which need not be here given.

Similarly the demand charges of the different lighting and power classes are divided in proportion to peak of the class.

The total charges should be divided in any given case, first between the light and power classes as follows:

$$\text{Light demand charge} = \frac{\text{total demand charge} \times \text{light peak}}{\text{light peak} + \text{power peak}}$$

$$\text{Power demand charge} = \frac{\text{total demand charge} \times \text{power peak}}{\text{light peak} + \text{power peak}}$$

Each class demand charge is determined then by proportion of substation class demand to total class demand as shown in Fig. 2. This Fig. 2 will illustrate the matter without further examples. If the demands are not the same, use the above formula for determining demand charges to classes.

In California we must provide for storage three months per year. That is, about one fourth the total annual kilowatt-hours of the system must come from storage water, or its equivalent steam reserve power. Now steam reserve power costs about 0.4 cent per kw-hr. for fuel and water at the steam plant and naturally this is a measure of the value of the storage water. If one-fourth of all kilowatt-hours comes from storage water and is worth 0.4 cent per kilowatt-hour this then means an energy cost of 0.1 cent per kw-hr. spread over the entire 60,000,000 kw-hr., or $60,000 per year, as given in Fig. 2.

Instead of spending the money on water storage it may be expended on a steam reserve plant. The result is the same if steam plant yearly charges are $60,000 per year. For the different streams we may have energy charges varying from zero up to, say, the energy cost of the steam reserve plant.

In the above case instead of installing 15,000 kw. in the water power, we may install only 10,000 kw. in water power and install 5000 kw. in the steam reserve plant. Assuming that the total fixed charges are the same, Fig. 2 applies to this case if the energy charge for fuel and water is 0.4 cents per kw-hr. and we produce one fourth the total kilowatt by means of the steam plant.

Fig. 3 shows the relative rates to the different classes with total yearly charges constant, but varying energy charge, and shows the importance of proper relative rates for the particular conditions. Instead of a water-power plant we may have a 15,000-kw. steam plant costing say $1,400,000. Fixed charges

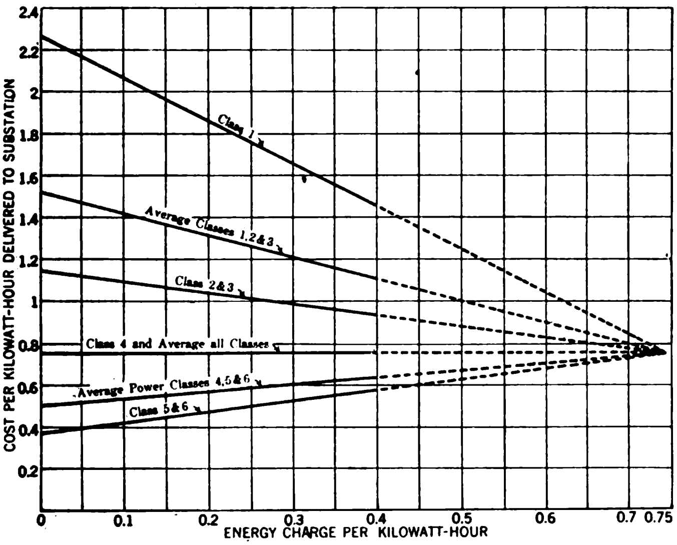

FIG. 3—CLASS RATES AT SUBSTATIONS AS VARIED BY ENERGY CHARGE

Peak demand of four large classes equal.
Total yearly charge $450,000.
Energy charge varies from 0 to 0.75c. per kw-hr.

Class	Kw-hr. at Sub-station
1	5 million
2 & 3	10 "
4	15 "
5 & 6	30 "

Equation of straight lines:

y = total rate, x = energy charge in cents per kw-hr.

$$y = \frac{45{,}000{,}000\text{ c.} - 60.000{,}000\,x}{4 \times \text{class kw-hr.}} + x$$

For class kw-hr. = 5,000,000 we have:

$$y = \frac{45{,}000{,}000\text{ c}\cdot}{4 \times 5{,}000{,}000} - \frac{60{,}000{,}000\quad x}{4 \times 5.000{,}000}\,x + x = 2.25\text{c.} - 2x$$

Note: The figures assumed for kw-hr. are taken to make problem simple for illustration. Load factors for Classes 5 and 6 are 20 to 30 per cent higher than usually obtainable and hence rates for these classes are 20 to 30 per cent low compared to other classes.

would be say 15 per cent or $210,000 and energy charges at 0.4 cent per kw-hr.:

0.4 cent × 60,000,000 kw-hr................	$240,000.00
Fixed charges..............................	210,000.00
Total......................................	$450,000.00

There are greater differences in cost of service in different sections of a single city for the same class of service than there are between cities of the same class in one large system. In a city the grocer and butcher do not vary charges by distance of delivery. That would breed all kinds of trouble. Similarly, electric service of a certain class should be standard throughout a city, even though the cost for energy and investment may vary 10 to 30 per cent. A uniform rate is essential for simplicity and to avoid any appearance of discrimination. Wherever the general rules for connections and service apply to a city the charge should be the same for the same class of service. Underground and overhead will have different schedules of charges and there will be different schedules for different classes of light service as well as different class of power service.

It is believed to be as essential to carry this principle over the entire system. The overhead residence lighting service of towns throughout California, except perhaps the large cities like San Francisco and Los Angeles, is nearly enough the same to warrant a uniform rate. The same is true for other classes of service.

Some axioms or general principles will at once be evident, as has already been pointed out, as a result of a study of the system and system power curves.

Similar service in different communities should be charged for at the same rate. For example residence lighting in Sacramento and Stockton should have the same scale of rates—except as local costs of overhead and underground distribution may vary, or where natural conditions or competition may have produced unusual conditions. And it is believed that residence lighting in these cities, as well as such towns as Chico, Marysville, Woodland, Santa Rosa, Petaluma and San Rafael, should have one scale for overhead distribution and one for underground. Rather than have a large number of different scales with slight differences it is believed it will be better to have a uniform scale. A sliding scale would take care of quantity consumption.

Similarly a farmer pumping water for irrigation with a 20-h.p. motor near Woodland should have the same rate as a farmer requiring the same service near Marysville. A machine shop in Richmond using a 50-h.p. motor should have the same rate as one in Antioch, etc., etc.

The same is true of all classes of consumers. It is believed it is better for all concerned to have uniform average class rates with a sliding scale than a large number of different rates for each class.

Inquiry into rates then would take the line of investigation of determining the "class rate" for the entire system, and would not take each town or district supplied from a substation and fix rates in that district for the entire class. As time goes on the different districts will merge together and differences in rates must in the end be done away with.

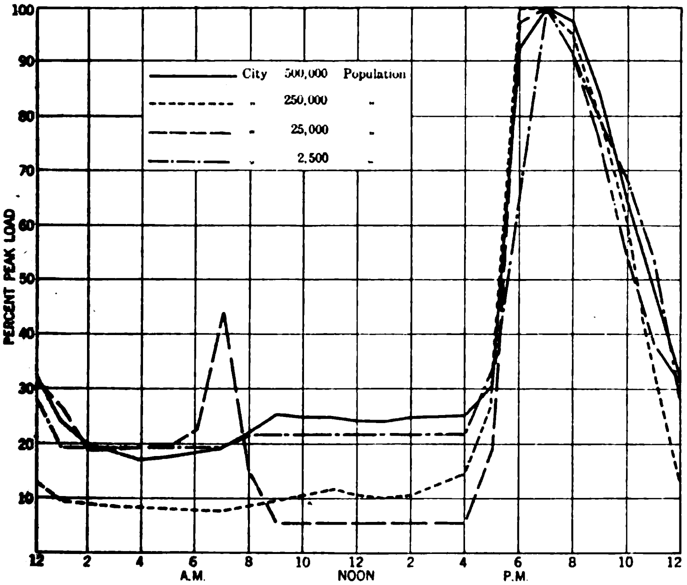

FIG. 4—DAILY LOAD CURVES, COMMERCIAL AND RESIDENCE LIGHTING, SHOWING SIMILARITY OF CLASS 1 DEMAND

An inquiry into the lighting rate in Oakland and Berkeley for example, might lead to a different rate for lighting on the same street. This is of course absurd. Similarly a foundry in Sacramento on one side of a street should have the same rate as that on the other side, if their service requirements are the same. It makes no difference if the two foundries are served by different companies.

In other words, rates would be investigated and fixed by classes to correspond to the judgment of the rate fixing body as to what is the proper rate for that class when considering the class of service, the different costs to different companies to supply that service, and the general question as to whether the particular industry of the class tends to develop other business and make for a prosperous community or state.

Inquiry into the reasonableness of railroad rates does not lead to the inquiry as to rates for all classes of service to and out of a city or town, but inquiry must necessarily question the reasonableness of certain classes of service.

Further, class rates worked out for an entire system will necessarily be more stable than where worked out locally. Rates would then not change because a new substation or distribution system was installed at some local point, but rates would be determined for the entire system's investment and operating conditions. Necessarily the variation in an entire system's condition is small.

The passenger rate to Sacramento is the same over the Southern Pacific or Western Pacific Railroad, although the latter is longer and costs more; the railroad rate does not vary to Sacramento because a new bridge is erected or because new ties or rails are laid, or because a more economical locomotive or more expensive coach is used, or because a new depot is erected at Oakland. Rates made to vary with these items would be absurdly changeable. The rate from Sacramento to Summit on the Southern Pacific is the same as the rate down from Summit, although in one case it requires oil to haul the train and in the other it coasts most of the way. The fare on a street railway is the same to the end of the line as for a shorter distance.

The entire power and distributing system can be maintained at a standard service condition while individual units or sections may vary in condition quite materially. It is not economy to maintain all the units at a uniform standard. The variations in condition over an entire system will be negligible when considering any given class rate, while locally there may be quite a wide variation at different times.

I am certain there is no more reason for having different scales for the same electric service in Napa, Petaluma, Santa Rosa or San Rafael because of different states of newness of the distribution system, than there would be for the Southern Pacific Company to vary the railroad rates between these towns because it renewed the ballast, or ties, or rails on certain sections of the track, or operated a more or less economical engine, or because one or more of the towns had more or less new depots. The variations in rate would be ridiculous for these reasons.

If this is the condition, then the relative rates of power for the different classes are to be taken along the vertical line of 0.4 cent energy charge shown in Fig. 3.

Figs. 2 and 3 show it is not equitable to charge the same per kilowatt-hour to all classes; in fact it is clearly shown that discrimination will result from such a practise to the detriment of the power business generally, with the result that the entire business will suffer and the lighting rates must increase because the power business will not develop. It is also shown by Fig. 3 that relative rates to be equitable must be determined for the actual energy charge for the system.

Having determined the amount of the energy charge E and having the total amount T to be earned by the system to the substations, the demand charge is $D = T - E$.

This demand charge D is then proportionately charged to the several classes as shown in Fig. 2. This gives $T = D + E$ (total charge to any class equals the sum of demand and energy charge of class) for any given class up to the substation.

This system of apportioning demand charges in proportion to the peak demand of classes develops largely automatically the relative "value of the service" to the different classes of consumers. The power consumer pays the same per 24-hour day per kilowatt demand as the lighting consumer. In other words the "value of the service" of a kilowatt demand is worth practically a fixed amount per year to all users independent of the length of time it is used. That this is fair and scientific has been shown, and the application of the system produces relative rates (see Figs. 1, 2 and 3) which will develop the business. With relative rates between classes determined as shown herein, the occasions for making special cases will be the exception, rather than the rule, as at present. Most business will fall naturally into the general classes.

To determine finally the total cost to consumers for any given class we must know the cost of service for each class from the substation to consumers. This would require that separate accounts be kept by classes for the entire system. Records of demands and kilowatt-hours consumed by different classes would also have to be kept. Where power and light are on the same cirucit the load curve must be analysed as in Fig. 2 to get at the proportional charges.

Fig. 3 brings out very clearly the relation of the relative cost of power at substation for various classes of consumers for varying energy charge.

If there is no encouragement to develop water-power energy, charges must be taken under steam plant conditions, that is at about 0.3 to 0.5 cents per kw-hr. If relative rates are taken under water-power conditions then encouragement must be given to develop hydroelectric rather than steam power. If we offer 8 per cent to the company that develops steam power we should offer more than 8 per cent to the company that develops water-power. Otherwise it is plainly evident that for the same interest return there will be little water power development. The largest rate of return should be for investment in storage water, as the public obtains, in addition to the general benefits from the water power development, large indirect benefits from storage water, due to the fact that the stored water becomes available for irrigation, and increases the low water flow of navigable streams.

It is believed the above method of determining demand and energy charges is correct and it is also believed that if each class of consumer is made to bear his equitable cost that we naturally and automatically bring the "value of the service" into account. Rates so determined will naturally develop all normal business. There will be cases where special inducements must be made to get the business even if it does not earn 8 per cent on the investment, as pointed out in my previous paper on "The Best Control of Public Utilities." Some other business must make up the difference.

UNIFORM CLASS RATES FOR A SYSTEM OR TERRITORY

Uniform class rates for an electric light and power system or territory are advisable where one commission regulates rates.

The above applies where the rate must be fixed for a city, town or district. Where the rate regulation for the entire system or territory is in the hands of one body, much better results will be obtained by considering the system as a whole. I believe the necessity for uniform class rates is so great that I shall go into the matter in some detail.

Before the time of electric transmission the electric business was practically confined to the lighting business. In small towns the local steam plants supplying the lighting usually operated from about 5 p. m. to about midnight. In larger cities the plants operated during the entire 24 hours. Very little power business was done, with the result that the main business was done during the lighting hours.

None of these early electric companies were very prosperous the main reason being the limited earnings due to the limited use of the plant, that is, to the low load factor of the lighting business, usually from 10 per cent to 20 per cent.

With the advent of electric transmission from the water power plants the managers of these properties, seeing the investment idle or without load during most of the day, and interest and maintenance charges and operation costs being practically fixed, independent of the load, began to look around for some business. Day load was sought and low rates had to be offered in order to induce the factories having steam engines to discard these and purchase electric motors and electric power. The success of the electric motor and electric transmission of power are responsible for the large economic gain obtained as a result of this change of the individual power plant to the universal electric power system.

It is the factory load that has made a financial success of electric transmission. I believe that the economic gain to the country due to electric power is only comparable to the gain as a result of railway transportation and the gain due to modern systems of agriculture. We have in California many communities which owe their beginning and development largely to electric transmission. It is, therefore, important that the reason for various costs of service on different classes of electric business under the conditions be thoroughly understood.

There have been considered class rates applied to each city or district of a system. This method is necessary where the regulation of rates is controlled by local bodies, or a local company supplies the service. With the passage of the constitutional amendment placing all cities under the commission in California, a much more logical and satisfactory system of rates will result by considering rates for a given class for an entire system or territory for similar service. This will not only be more just to different classes of consumers, but immeasurably simpler in application.

In regulating rates for the different consumers in a city it has been found best and necessary to make uniform rates independent of the difference in cost due to different distances from the central station to the consumer. It has also been found advisable by the California commission (and I believe the principle necessary in practise under the conditions) to disregard the small variation in transmission costs and assume uniform power costs independent of distance from the power source. It is only a short step to a consideration of a uniform rate for similar class of service throughout a system or territory.

Why should the residence lighting rate in such towns as Chico, Marysville, Woodland, San Rafael, Santa Rosa, Napa or Petaluma be different for overhead service or for underground service? And why should Chico's rate be high this year, Woodland's low and Petaluma's lower because perhaps the distribution system is new in Chico, a few years old in Woodland and a little older in Petaluma? In a few years the conditions may be reversed but rates could probably not be raised. Is it not better to determine average rates for the entire system for this class of service and apply it in all these cities? The distribution systems are all being maintained at the most advantageous point for economy as a whole and the service is constant.

And why should the service charge in one city be reduced because a more economical turbine is installed in that city and increased for the wasteful engine allowed to remain in another? Why should the rate be reduced for the company having an efficient organization and economical construction, and raised for the company having an inefficient organization and wasteful construction?

The principle is incorrect and must lead inevitably to failure. On the other hand, apply uniform class rates for certain kinds of service, independent of the particular town or consumer being served and independent of which company gives the service, and we immediately have an incentive for the company to make economies and to reduce cost of construction. For, if the charge for a given class of service in a given district is fixed, the company having the lowest costs will benefit most, and vice versa. This principle is vital for economy and success.

The characteristics of residence lighting (varying for overhead or underground service) are nearly enough the same to make the rate uniform, and a sliding scale of rates will take account of quantity consumption variation of rate to the individual consumer. The same is true for street lighting and commercial lighting. Similarly the characteristics of industrial or day power are nearly enough the same to apply one sliding scale of rates throughout the entire district covered by the system. The same is true for railway and 24-hour power.

And naturally the rates for a given class of service should be nearly the same throughout fairly well settled parts of California where the service is available.

If a consumer requires an investment to give him service not covered by the general rules, he should pay the difference necessary to bring his case within the rules. Then his cost of service would be the same as other users in his class. Irrigation and reclamation rates should also be uniform except for extraordinary initial costs to supply the consumer and these the consumer should pay.

To get the lowest rates for all classes it will be necessary to take on some classes of business that may pay only a small per cent on the investment. This is at once evident, as has been shown, by examining the system load curve. If we could sell the surplus power available from 12 p.m. to 6 a.m., even if sold for less than one-half a cent per kilowatt hour, the earnings of this period would be nearly all profit, that is, it would subtract nearly that amount from the other consumers. Practically the only cost of the service to the power company would be for oil if from a steam plant and for storage water, if needed, from a water power plant.

Similarly to sell day power it must be sold at less than it would cost the consumer to produce it, at the same time the company must earn part of its fixed charges and the tendency of the business taken on must be such as to reduce the general level of rates as the volume of business increases.

The problem of finding the proper rates to be charged each class is a simple matter, as shown by Figs. 1, 2 and 3. We would first determine the total amount of fixed charges to be earned to the substations and proportion this amount to the light and power classes as given previously. We would then determine the amount of the peak demands of the different lighting classes and the power classes, the amount to be earned to the substation can be apportioned to the classes. Then having a segregation by classes of the investment, maintenance, depreciation and operation expenses (excluding oil or storage water) we can determine the amount to be earned for fixed charges for each class for distribution including the substation. Adding the cost up to the substation to the distribution costs and finally adding the energy charge, we determine the total charge against the class. We then divide this total amount to be earned by a class by the kilowatt-hours consumed by the class, as shown by the consumers' meters, and we have the average kilowatt-hour charge for that class: It remains then only to determine the sliding scale of rates which will earn this average rate as determined, considering the quantity consumption of different consumers.

The development of the small local electric company into the large company operating over a wide territory makes it necessary to discard the old practise of fixing rates for each local situation separately. This was necessary with local bodies fixing the rates, but a reasonable scale of rates can not be worked out for a large system without considering the entire system. We may as well try to work out separately the railroad rates for the Southern Pacific and Union Pacific from San Francisco tc Oakland, from Oakland to Sacramento from Sacramento to Ogden, from Ogden to Cheyenne, from Cheyenne to Omaha. The absurdity of this thing is apparent at once. We can not consider parts of an entire machine and estimate its earning value independent of the other related parts.

The electric system is a means of generating and transmitting power to a large number of consumers over a wide area. The system supplies energy for light to one class of consumers for one part of the day and energy for manufacturing, largely, during another part of the day and the natural subdivisions of the business are found, by a segregation of the total business into classes, just as has been found necessary in determining railroad rates.

There is nothing experimental about it and the further development of the electric power system depends largely on the initiation of uniform class rates, for systems or territories where similar conditions exist.

ADVISABILITY OF UNIFORM CLASS RATES

The advisability of determining class rates by considering the *natural* divisions of the *classes* of business rather than considering the more artificial division into territories or towns served by certain substations will be admitted by anyone making an impartial study of the situation.

By considering the local situation in a town or district the tendency will be to largely disregard the effects of the local situation on the remainder of the system. This method accentuates the " cost of service " and practically ignores the " value of the service " or the " reasonableness of the rate " from the consumers' standpoint.

On the other hand by considering the *classes of business* and trying to determine average class rates for the system, I think there will be a direct tendency to have the " rate makers " consider " value of service " and " reasonableness of the rate " from the consumers' standpoint. For in considering the " class " there must be always brought to mind the entire system, and this will naturally bring to the minds of the commissioners the effect of certain classes of business on the company as a whole, and will accentuate the necessity for giving low rates for certain class of service, even though this class can only earn a part of the fixed charge.

And inevitably, we can see that the application of class rates will lead further than this, for it is not a far step from the determination of average class rates for a system to a *system of class rates which will make the rate for a given class of service the same* even if the service is in Stockton, Sacramento or Oakland or anywhere in the territory, and even if supplied by different companies. And for the company that has done economical construction, has a good organization and operates at low cost this method must be to its advantage.

Analyzing rates to and out of each substation must necessarily give different rates for the same class of service to adjacent areas, (or in the same area where supplied by two companies) as the district lines are now largely imaginary and ultimately all districts will merge into one. And as stated above, in analyzing and fixing rates for the substation area, the natural basis of fixing rates *is* this " cost of service," leaving the " value of service " and the necessity of developing a general diversified business for the entire system (which tends to give the lowest cost to all consumers) largely unconsidered.

On the other hand, analyzing and fixing rates by classes will tend to make rates uniform throughout the territory served (except for special cases where extra investment is necessary) independent of the town, district or company supplying the service. This must tend to fix the minds of the commission on the " value of the service " and the " reasonableness of the cost " when considering other companies or from the consumers' standpoint. The necessity for considering other companies and their costs must result in rewarding the company having the lower costs.

In analyzing rates, the substation, town or district is not the important or correct subdivision, but instead a certain rate applying to and developing a certain class of business is the important thing to be analyzed. This naturally requires that the entire system be considered, and also consideration to be given to the effect of the rate in one class affecting the rate in another, and the effect of the rate on other companies and other localities must be kept in mind, all of which will benefit the economical company as it should.

Hence there is brought continually to the mind of the investigator of rates, the necessity for developing certain classes of business as well as the cost of supplying the business. And as certain classes of business must be taken on at low rates (lower than will earn 8 per cent) this method of fixing rates will tend to accentuate and keep in mind the " value of the service " and the " reasonableness of the rate" from the consumers' standpoint.

Analyzing and fixing rates by cities or districts is a relic of the time when different local companies owned the local system. With a general system as a result of the transmission power, there is no more (and probably less) reason for considering the different towns separately than there is for considering each consumer in a town separately, and making the rate vary as his distance from substations. The latter would add immeasurably to dissatisfaction and complications, and having different rates in different towns for the same service is as objectionable.

Summarizing the advantages; *average class rates* for the entire system:

(1) Will tend to have " value of service " and " reasonableness of rate " given consideration when fixing rates.

(2) Will make one rate for entire district for one class and hence give advantage to company having the lowest cost.

(3) Will tend to reward the efficient company and hence tend to reduce costs of service.

(4) Will tend to allow constant service value of the property of the system as a whole.

(5) Will very much simplify rate making.

(6) Will remove the differences in rates which cause most dissatisfaction and causes most rate inquiries.

(7) Will tend to make rates stable over a period of years.

On the other hand, analyzing costs to and from seperate substations, towns and districts:

(1) Will tend to make " cost of service " control the rates.

(2) Will give different rates in different towns and districts and will give higher rates to the company having higher costs.

(3) Will penalize the company having lowest costs and hence tend to increase cost of service.

(4) Will tend to make changeable local value of property the basis of return.

(5) Will very much complicate rate making.

(6) Will promote differences in rates which are the cause of most dissatisfaction and most rate inquiries.

(7) Will make rates unstable at all times.

CONCLUSION

The application of (uniform) class rates for a system or territory will therefore tend (1) to make rates simple, fair and definite, (2) equitable as between classes of consumers, (3) uniform so as to make them standard for similar conditions, (4) tend to produce economy in construction and operation, and hence, as a result of above, (5) rates will tend to be reduced as the volume of business increases.

Presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915.

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(*Subject to final revision for the Transactions.*)

THE THEORETICAL AND EXPERIMENTAL CONSIDERATION OF ELECTRICAL PRECIPITATION

BY A. F. NESBIT

Abstract of Paper

Theory of electrical precipitation of suspended matter in gases is inseparably connected with the phenomena of ionization and the laws of electrically charged bodies.

The motion of the suspended particle is like that of the charged pith ball in the familiar experiments, but the charge is obtained by ionization instead of contact.

The paper shows that electrical precipitation occurs in nature and then by calling attention to the structure of matter shows how ionization is brought about, how the ions, nuclei and aggregates are formed, and the final precipitation of these is effected by gravitation and the electric field.

Experimental apparatus for electrical precipitation is given and attention is called to the differences between the appearance of the positive, negative and alternating corona.

The experimental data have shown the superiority of the negative corona and the relative effectiveness of the size and shape of electrodes, temperature and conductance of gases, polarity and uniformity of corona.

Introduction

THE theory of electrical precipitation of suspended matter in gases and liquids is inseparably connected with the phenomena of ionization, and the laws of electrically charged bodies. In order then that we may become familiar with the facts that underlie electrical precipitation, it has been thought best to give a somewhat detailed outline of the present theories of ionization, followed by the results of experiments made to study the phenomena.

Everyone is familiar with the experiment in which a pith ball is brought up near a body negatively charged. The near and far sides of the pith ball accumulate positive and negative charges of equal magnitude respectively. This polarization or separation of the electric charges, constituting the neutral state of the pith ball, into the respective components, and the greater or less freedom with which either of these components may become detached from their holder, the pith ball, and become attached to, or else remain free

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from other material molecules, represent phenomena which occur in splitting up the molecule or group of molecules in its neutral state into its electronic and ionic components respectively. This analogy is helpful in getting a correct view of the migration of charged bodies in an electric field; but the cause of the charge, the structure of matter, ionic migrations, and ionization agents must be considered at the outset.

As shown later, the particles suspended in a gaseous medium or constituting the solid and liquid particles of a moving gaseous stream, whenever they are subjected to the action of intense electric fields, become charged by the action of the traveling ions and electrons and consequently tend to travel along with these ionic streams.

1. THE GENERAL PROPERTIES OF PARTICLES SUSPENDED IN GASES

Light reflected from very fine particles held in suspension in a gaseous medium is usually of a bluish color, and this color is purer the smaller the particles. As the particles increase in size, the reflected light becomes a pale blue and finally white when all wave lengths are equally well reflected. This phenomenon is observed on an enormous scale in connection with the blue sky, the brilliant sunsets, electrical discharges during thunder storms, and during the occurrence of the Northern lights, and shows the presence of suspended particles. The presence of atmospheric dust and moisture, along with the electrical phenomena which are taking place in the earth's atmosphere, is largely responsible for the precipitation of the so-called floating particles in the air. This is electrical precipitation occurring on an immense scale in nature.

The problem to which our attention is here called, is that which undoubtedly accounts in a large measure for the meteorological phenomena of the condensation of suspended water particles into rain, the formation of fogs and mists, the formation of snow, the presence of ice crystals at high air elevations, and the electrical phenomena occurring at these same high altitudes. The combined effect of these natural phenomena, with the presence of floating particles of man's own making, have an important bearing on climates, vegetable and animal life.

2. THE ATOMIC STRUCTURE OF MATTER

The modern theory of matter is that it is composed of atoms, each one of which is of the same size. Likewise, charges of electricity are composed of the so-called electrical atoms, each of which is made up of the same quantity of electricity. The molecules of all material substances, whether gases or fluids, when in their neutral state, are said to possess equal quantities of positive and negative electricities.

Recent investigations and deductions furnish evidence which leads to the view that at least a part of the mass of an atom of any element is of electrical origin, and that the atoms of different elements differ only in the number and grouping of the ultimate units of negative charge called electrons. The electron represents an amount of negative electricity equal to 4.8×10^{-10} electrostatic units. No accepted name has been given to the ultimate unit of positive electricity corresponding to the electron, because no exact information is available as to the way in which positive electricity exists in the atom.

When an electron has been added to a particle or molecule of any substance, in the neutral state, it is then said to possess a free negative charge of 4.8×10^{-10} electrostatic units. When an electron has been removed from a particle or molecule, in the neutral state, it is then said to have a positive charge of 4.8×10^{-10} electrostatic units.

3. IONS, NUCLEI, AGGREGATES

Experiments on the electrical conductivity of gases, suggest that this property of gases is greatly increased by raising their temperatures. This fact, coupled with the statements made above, leads to the conclusion that the molecules or particles of the gases themselves, apart from any suspended solid or liquid matter which they may contain, become better conveyers of electricity as their temperatures are raised. These charged particles or molecules of the conducting gas, or the suspended particles of vapors, dust, fumes, etc., which it may hold in suspension, are called ionized particles and some are charged positively, others negatively, the two kinds of charges not necessarily being of equal magnitude.

A negative ion, or a carrier of a negative charge, is formed when a neutral molecule of a material substance, such as a particle of dust, vapor, or smoke, has imparted to it from any source whatever one or more electrons in excess of the number contained in its neutral state. The magnitude of the charge on the negative ion depends upon the number of electrons which have been added to the neutral molecule, or aggregate. In like manner, a positive ion is formed when a neutral molecule or aggregate of a material substance has one or more electrons removed from it.

These ions themselves may become the centers or nuclei about which large aggregates of the particles of the body may be clustered or assembled, and their charges may in part neutralize each other, or give rise to increased potentials for the aggregates above that of the individual ions.

An illustration of this principle on an enormous scale is the usual consideration of the myriads of minute water particles floating in the air. The clouds are great masses of water vapor, dust particles, and other floating matter in the air. This floating matter may exist more or less in the form of aggregates. The aggregates may have been formed by the condensation of water vapor on the dust or other particles as nuclei, or during their fall due to gravitation they may unite to form small drops. The drops of water are more or less charged with positive electricity, probably due to evaporation taking place at the surface of the earth and upon bodies of water.

When condensation centers begin to form, the aggregates have a resultant charge equal to that of the individual particles composing it. Thus, when an aggregate of eight water particles is formed into a sphere of twice the radius of the individual particles, that is, into a sphere of twice the electrostatic capacity, the potential of the aggregate is raised to four times that of the original particles.

4. IONIZATION

By ionization is meant that process by means of which the molecules of matter are split into positively and negatively charged particles or positively charged particles (ions) and electrons. The principal ionizing agents are Roentgen and Becquerel rays, cathode and other rays, the electric field, high temperatures, ultra-violet light and chemical action.

The phenomena of ionization are considered under the four following heads:

a. *The Action of High Temperatures.* When the temperature of a body becomes sufficiently high, the velocity of some of the electrons is so large that their excursions carry them beyond the surface of the body and they escape into the surrounding medium. Simultaneously with the escaping of the electrons from the hot or incandescent body, there may be emitted particles or molecules of the body itself, and these particles with their associated negative and positive charges constitute the streams of negative and positive ions.

b. *Thermions. Thermionic Currents.* In the case of hot or incandescent bodies, the ions which are emitted are called thermions. The density of these ionic streams constitutes what is called the density of the thermionic currents, and depends upon the physical and chemical conditions of the hot body at the time, its temperature, and the properties of the medium into which the ions are emitted or radiated. This thermal ionization from the fuel and the hot surfaces in the furnace or fire box may aid somewhat in giving an initial charge to the particles with which we are concerned in the electrical precipitation of smoke.

c. Chemical action may be the cause, as well as the result of ionization.

d. *Ionizing Action of Water Sprays.* Wilson[1], Eve[2], Pomeroy[3], and others have investigated the ionizing action of fine jets of water in the form of sprays, and the conclusion is reached that both negative and positive ions are produced, the former being slightly greater in number than the latter. It may be possible that the ionization produced by water jets may have some valuaable effect in the removal of suspended matter in air washers. The positively charged ions are associated with the heavier parts of the spray. The electrons, however, seem to attach themselves with great difficulty to water drops even though they be of very small sizes. These facts may explain the positive electrification of atmospheric clouds as due to evaporation of water.

Armstrong[4] studied the electrification of steam jets, and one of the conclusions he reached is that the electrification developed did not appear to depend upon the degree of violence with which the steam came into contact with the air. The work of Armstrong may shed some light on our subject.

THE THEORY OF ELECTRICAL PRECIPITATION

In general, solid and liquid particles may be considered as susceptible to the action of either or both the electric and magnetic fields. Only a few kinds of particles are acted upon by the magnetic field, and the most important application of the magnetic field is in the separation of iron ore dust from the earthy subtances with which it occurs in nature. We must keep in mind that every electromagnetic field is made up of its two inseparable components, the magnetic and electric fields respectively. Since the action of the magnetic field depends upon the more or less polarization of the particles to be removed, and is accounted for in a manner similar to that which explains the phenomena associated with the electric field, it will not be discussed in this paper.

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[1] *Philosophical Magazine*, July 1902.

[2] *Philosophical Magazine*, p. 382, 1907.

[3] *Physical Review*, 27, p. 492, 1908.

[4] *Philosophical Magazine*, Vol. 17, 1840.

Material particles, for our purpose, may be grouped in two classes, conducting and non-conducting. When the conducting particles are brought into an electric field, they immediately take up a definite redistribution of their charges which constitute their neutral state; each side of the particle has an accumulation of positive and negative electricity respectively, and it is customary to represent this condition by saying that the electric field has polarized the particles. Independent of this polarizing action, there may be either or both positive and negative ions, and electrons present in the field, and these ions and electrons as a result of collisions among themselves and with the polarized particles will tend to combine with the latter and form what are called large ions or aggregates. Ions of this type are continually yielding up or receiving charges, and in a medium in which the density of the suspended particles is very great and the particles of minute size, it is quite probable that the formation of aggregates is hastened by the polarizing action. The velocity of the large ions is very small, and such being the case, special consideration must be given to these facts in the design of a precipitator to treat such particle-laden gaseous streams.

It may be inferred from what has previously been said, that the greater number of possible applications of electrical precipitation is concerned with the treatment of gaseous streams laden with solid and liquid particles of the non-conducting type.

RESEARCH WORK ON ELECTRICAL PRECIPITATION

Some idea of the phenomena attending the precipitation of suspended particles in gases by the electrical process was obtained by means of special apparatus as shown by Figs. 1, 2, 3, and 4. The glass cylinder, Figs. 1, and 4, six in. inside diameter, completely enclosing the quarter-inch wire-mesh cylinder five in. in diameter, was sealed to the lower glass jar and also to the upper glass jar or pipe leading to the suction fan. There was thus eliminated any possibility of an in-draught of air through the wire mesh cylinder which constituted the grounded electrode.

The wire *c* in Figs. 1 to 4 represents the active electrode of the system, and was placed axially within the wire-mesh cylinder, being supported at either end by means of heavy-walled glass tubes *dd*. Connection to the high voltage electrical circuit was made through the upper glass tube *d*.

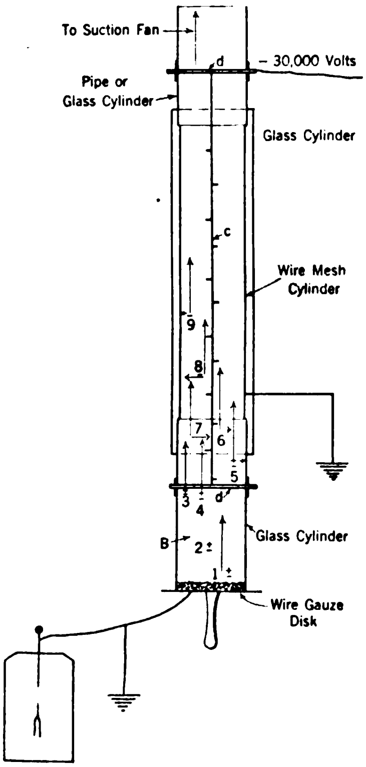


FIG. 1

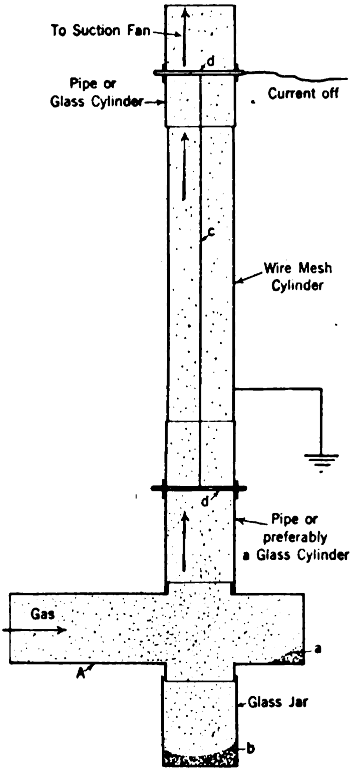


FIG. 2

In the experiments to be described, all cylindrical parts of the apparatus were of glass, except the wire mesh cylinder and the cross *A* of stovepipe in Fig. 2. Ample insulation was thus provided against any leakage of electricity from the active electrode *c* to any part of the apparatus, except corona discharge between the wire *c* and the grounded wire-mesh cylinder.

The electrical circuit consisted of a high-voltage transformer capable of stepping up from 220 volts to as high as 80,000. The high-voltage side of this transformer was connected through a mechanical rectifier of the Lempe type, and one side of the circuit was taken to the upper end of the active electrode *c*, the other side going to ground. A potential of about 30,000 volts was needed to get a strong negative corona discharge from the wire *c* toward the wire gauze.

Referring now to Fig. 1, very fine pieces of thin tissue paper, tin foil and gold leaf, fine shreds of silk fibre and other light substances were placed on the wire gauze disk. Every precaution was taken to insure that these particles of paper, etc., were free from any electrical charges, the disk being first connected to a delicate gold leaf electroscope, which gave no indication of charges, and then grounded.

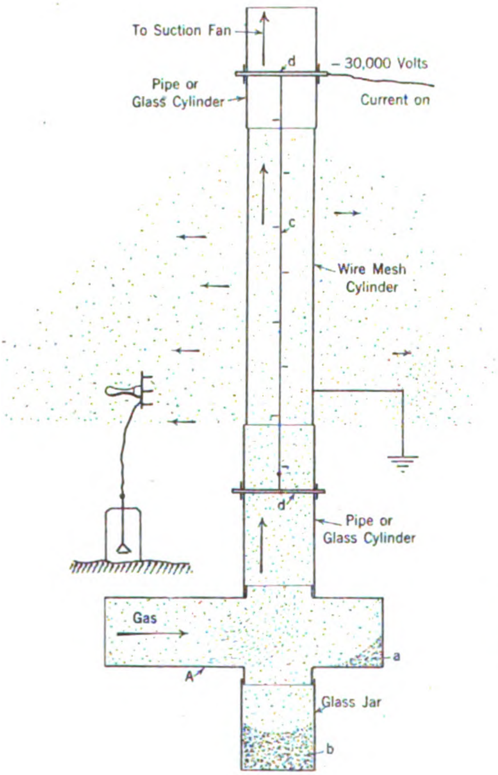


FIG. 3

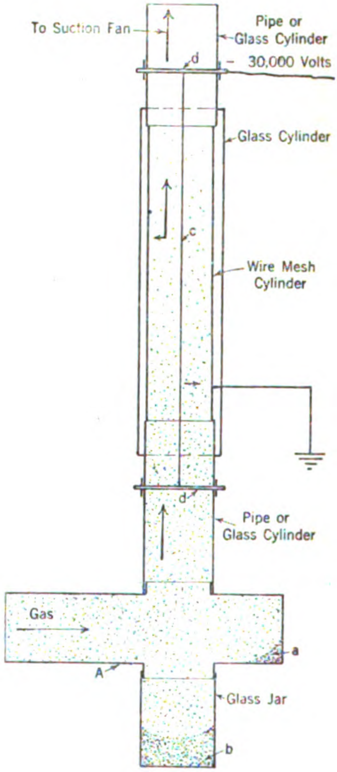


FIG. 4

When the electrical circuit was open, and a gentle suction applied by means of a fan connected to the top of the apparatus, the light pieces of paper, tin foil etc., were lifted off the wire-gauze disk, and floated lazily along through the wire-gauze cylinder without any definite or prescribed course. Some of these particles jostled against their companions and aimlessly wandered along the with gentle current of air.

Upon closing the electrical circuit, however, these same floating or suspended particles evidenced a very distinct behavior; especially was this true between the wire *c* and the wire mesh cylinder. An immediate redistribution of the charges constituting the so called neutral condition of these particles evidently takes place. In accordance with the laws which govern the action of such light bodies when brought into an electrical field, the particles almost invariably flocked very quickly toward the wire *c*, only to be hurled, as it were, away from it an instant later and start on their journey toward the wire mesh cylinder, where the electric field was very much less intense.

Thus in Fig. 1, particles 1, 2, 3, and 4 have not yet experienced a redistribution of their charges constituting their neutral state. Particle 7 has its neutral state charges redistributed, and experiences an attraction toward the wire *c*. This particle will actually move toward *c* unless it is forced to move toward the wire mesh cylinder due to collisions with its companions, which, like particles 5, 6, 8, and 9, have had the positive charges of their neutral states already neutralized by contact with or a near approach to the wire *c*, and then are hurled toward the grounded electrode or wire-mesh cylinder.

When such particles have once reached the grounded electrode, they sink more or less aimlessly down the inner wall of this electrode, (provided they have not passed through the mesh), and finally reach the lower apartment *B*, where they may again be caught up with the ascending air current and repeat their experiences. The behavior of particles of finite dimensions, such as those described, is accounted for by the so called polarizing action here described.

When other particles become of very small size, of ultra microscopic dimensions, it is doubtful as to whether the polarizing action plays as prominent a part in the phenomena of electrical precipitation, as do the electron streams, or the coronal radiations and the accompanying secondary ionization which results.

In Fig. 2 the glass cylinder surrounding the wire-gauze cylinder of Fig. 1 was removed, and simultaneously with the application of a strong suction action at the top of the apparatus, a current of air laden with finely suspended particles was forced into the left end of the cross pipe *A*, as indicated by the arrow. The slight in-draught of air through the wire mesh prevents any appreciable passage of the suspended particles out through the mesh. As this experiment proceeded some of the particles carried in suspension in the gaseous stream were deposited, as at *a* and *b*.

Upon closing the circuit as in Fig. 3 a change quickly took place. The particles, which in Fig. 2 had been moving aimlessly along with the gaseous stream, were now acted upon by the electrical forces, because they were hurled bodily out through the wire mesh with considerable velocity, and to a distance of several feet. The polarity of those particles, which had not collided with the grounded electrode, or otherwise given up their negative charges while they were passing through the mesh, was easily determined by the gold-leaf electroscope.

The general appearance was that shown in Fig. 3, in which scarcely any of the suspended particles, for the given suction draft, traveled far enough upward to reach the upper end the wire mesh cylinder, and this took place notwithstanding the in-draught of air through the mesh due to the suction action applied by the fan. In this case there was a noticeable increase in the deposit at *b*. Referring now to Fig. 4, the six-in. glass cylinder encloses the wire mesh cylinder in the manner described in connection with Fig. 1. The circuit is closed as in Fig. 3, and the space between the wire mesh cylinder and the enclosing glass cylinder soon become filled with the particles which have experienced a motion radially out from the wire *c*, under the action of the electrical field.

When the suction fan alone is used to draw the particle-laden gaseous stream through the apparatus, the suction velocity may be so adjusted that no solid particles are present in the air or gas delivered from the suction fan. When this is the case, the space between the wire *c* and the wire mesh become more and more cleared of suspended particles as the top of the apparatus is approached, and the density of the suspended particles deposited in the space outside the wire mesh, is somewhat as represented by the depth of shading. Just as soon as this space becomes filled with solid particles, the continuance of this electrical action gives rise to a perfect shower of particles or aggregates of particles traveling down the inner wall of the wire mesh clyinder, and passing right through the ascending particle-laden gaseous stream, are deposited or precipitated as at *b*. Cold soot from soft coal, cold blast furnace dust, cement and alumina dust, and other fine particles have been tried with almost identical results.

Fig. 5 gives the general form of the rectified current wave used in these experiments. The central parts of both lobes of the cycle were used and the mean value was between one and two milliamperes.

THE PRECIPITATION OF SMOKE, CEMENT DUST, ALUMINA DUST, ASHES, ETC.

In the non-conducting type of particles or at least those only slightly conducting, is included a large number, of which the above are prominent examples.

In the presence of intense electric fields, and apart from possible initial ionization due to high temperatures of the gases, or chemical action taking place at high temperatures, the ionization, which takes place between the electrodes due to electronic and ionic streams, would sweep the particles to that part of the field which is the weakest, or strongest, depending upon their specific inductive capacitances. This weakest part of the field is located at that electrode which has the larger surface, such as is the case of a cylindrical pipe within which is placed coaxially a wire of small diameter. For a given length of such a cylindrical pipe, the suspended charged matter in the gaseous stream which is made to pass through the pipe, in order to reach the inner wall of the pipe before it passes out of the electric field between the wire and pipe, must move with such a velocity lengthwise of the pipe as will allow it to move in the same time a maximum distance equal to the radius of the pipe. Under these conditions, heavy aggregates, which move more slowly than finer ones, require a longer pipe of the same diameter for the same pipe velocities.

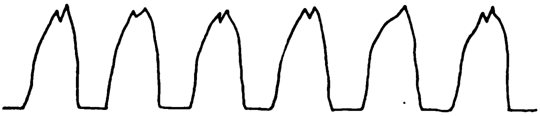


FIG. 5

A precipitator based on these principles was designed by Dr. Strong and the writer, and Figs. 6, 7, and 8 give the general appearance of the top of the outfit, when 900 cubic feet of coal smoke was moving through it, at a velocity of about five feet per second. Two circular groups of eight and seventeen piesp respectively, each pipe four feet long, and five inches in diameter, are firmly jointed to two end headers, to which the fine wires are attached, to keep them in rigid position. Fig. 9 gives a sectional view of this precipitator.

While it is understood that ionic streams may be produced in varying degrees of intensity by point, brush, and corona discharges, it is with the last named type of discharge that this precipitator operates. The positive and negative corona discharges, respectively, between the wires and the pipes as the active and grounded electrodes, for still air, are represented in Figs. 10 and 11. The original photographs were taken at night with the precipitator placed horizontally and the voltages employed were slightly less than the break-down values. When the wires as in Fig. 10 were maintained as the positive electrode by means of a mechanical rectifier of the Lempe pattern, the large patches or clusters of coronal glow, which constituted the positive corona discharge, occupied nearly the entire cross-section of the pipe.

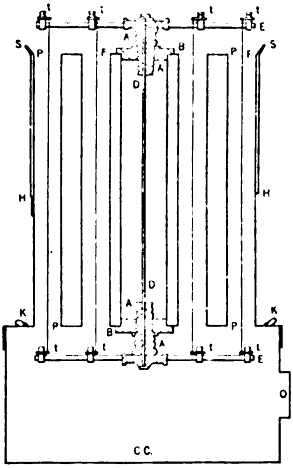


Fig. 9—Precipitation Chamber

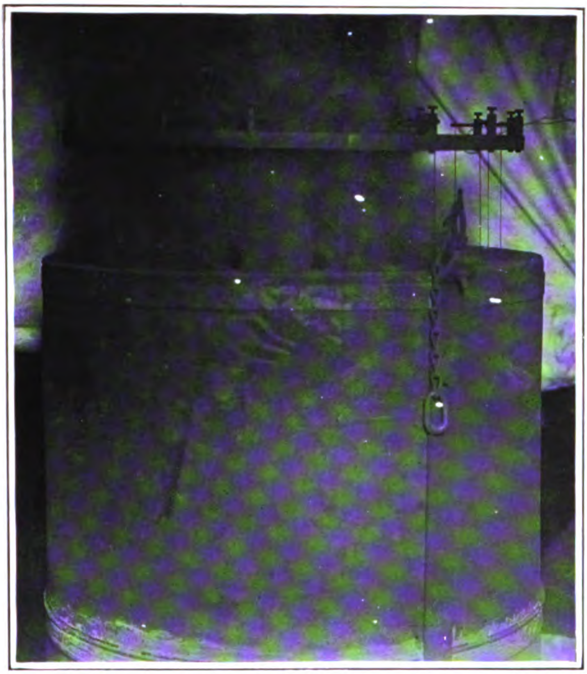
Fig. 11 shows the wire as the negative electrode. In this case the coronal glow is very limited in its depth radially, being at best only a few millimeters. Fig. 12 gives the appearance of the alternating-current corona.

Comparing the cleaning action of the positive and negative corona discharges with that due to an alternating corona, the following values give an idea of the relative efficiencies of the three kinds of discharges:

1. The alternating corona precipitates about 50 per cent of the suspended matter.

2. The positive corona precipitates about 70 to 80 per cent of the suspended matter.

3. The negative corona precipitates about 95 to 98 per cent of the suspended matter.



[NESBIT]

FIG. 6—OPEN CIRCUIT—NO PRECIPITATION

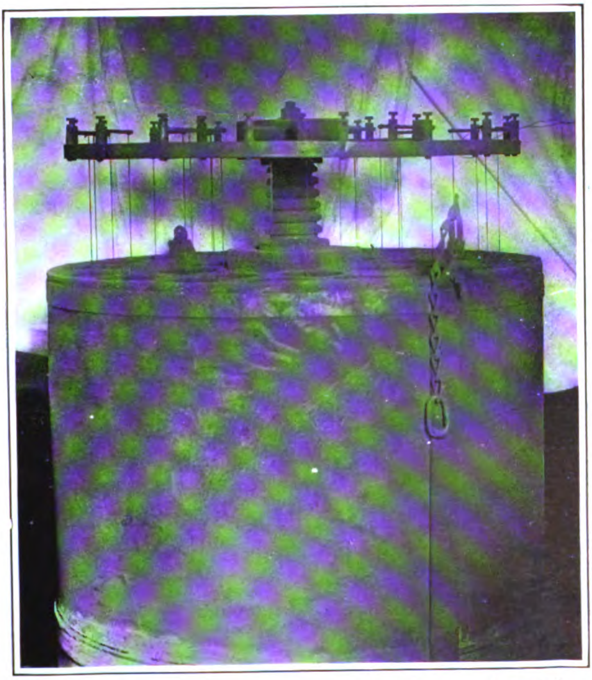


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FIG. 7—TWO FIFTHS SECOND AFTER CLOSING THE CIRCUIT

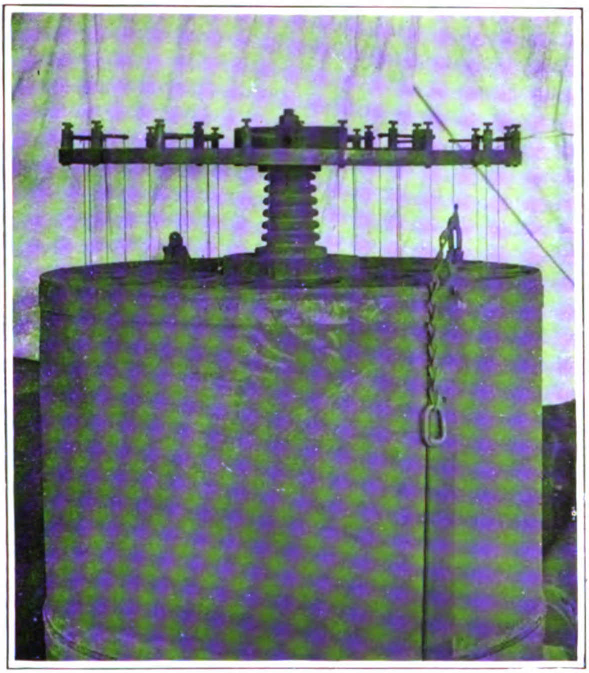

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FIG. 8—ONE SECOND AFTER CLOSING THE CIRCUIT
98 per cent clearance

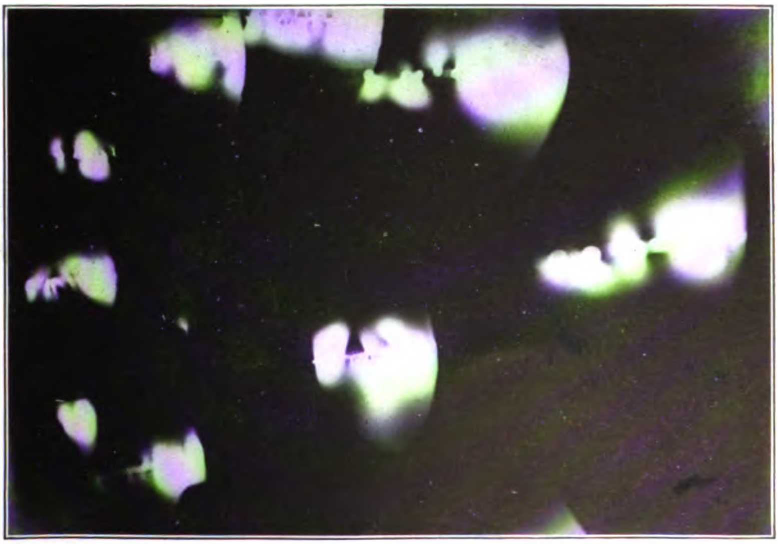

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FIG. 10—POSITIVE CORONA IN CYLINDRICAL PRECIPITATOR

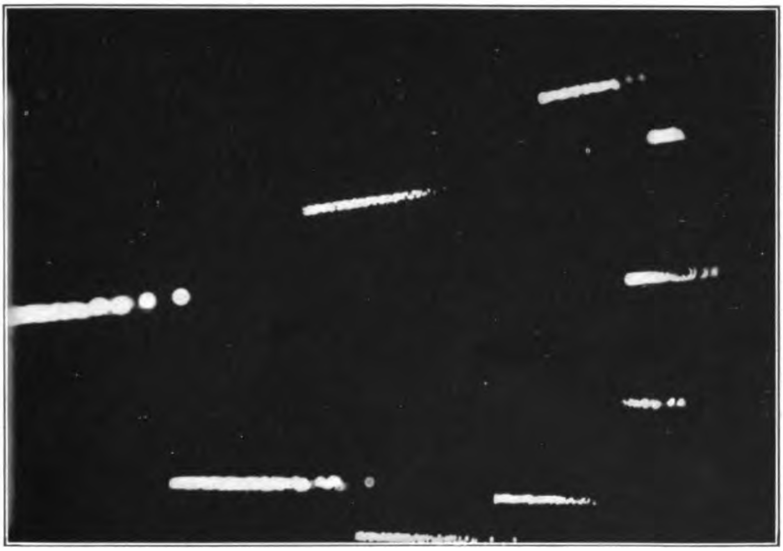

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FIG. 11—NEGATIVE CORONA IN CYLINDRICAL PRECIPITATOR

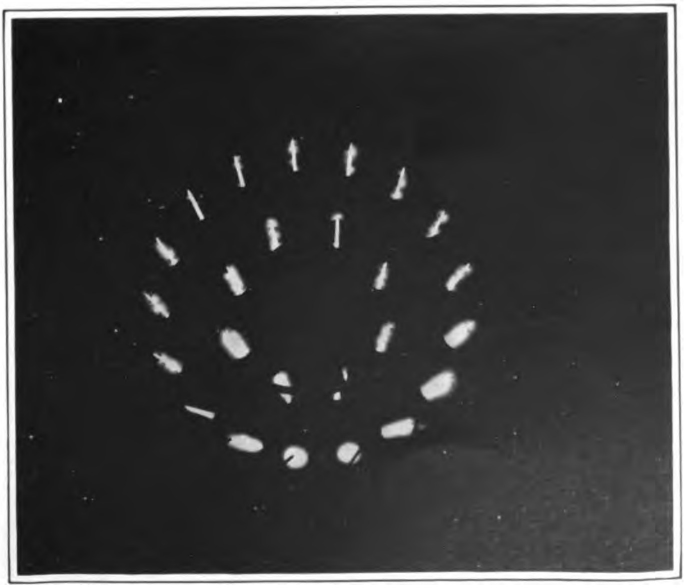

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FIG. 12—ALTERNATING-CURRENT CORONA IN CYLINDRICAL PRECIPITATOR

The unfitness of the alternating-current corona discharges arises from the fact that the reversal of the polarity of the active electrode, at which the field is very intense, results in a greater or less reversal of the direction of motion of the electrons and ions which are already on their journey toward the walls of the pipes. By this action many of the ions are more or less partially pulled back into the central region of the pipe, and before they ever reach the walls or an equivalent distance from the wire, the smoke or dust particles thus charged may have been carried out of the pipe and thus do not suffer precipitation. With hot air passing through the precipitator, and with a negative corona the breakdown voltage is somewhere near 32,000. For cold air the voltage was slightly greater. With a positive corona the voltage was lower with both hot and cold air. Very little difference in the voltages, from those given for cold air were detected in the use of cold smoke.

With smoke so hot that tar trickles down the central wire or active electrode, and also down the pipe walls, the voltage had to be decreased from 33,000 to about 28,000, in order to prevent violent disruptive discharges. Unless there is much moisture present, or the ingredients in the gaseous streams are sticky in nature due to their high temperature, there will be but little deposit on the electrodes. In any event, such a deposit suffers a tendency to be dislodged due to the slight vibration of the wire or the occurrence of a disruptive discharge of short duration. This variation in voltage must be brought about by a hand or automatic regulation, in a very short time, in order to avoid the establishment of an arc. If the impressed voltage is not too near the breakdown value, a disruptive discharge may continue for several seconds and then break, giving way again to the silent discharge.

The presence of fine points or irregularities on the inner walls of the pipes tends slightly to localize the discharge. Fine points due to hardened deposits, kinks in the wire, or rough spots on its surface very materially localizes the discharge from the active electrode; and even though there may be many such local discharges, the cleaning action of such discharges is much below that of the perfectly uniform field about a smooth wire although it may have considerable deposit on it.

Smoke, or other suspended particles contained in the gaseous streams, passes with considerable freedom from being precipitated through the positive corona, the alternating corona, or the localized type of discharge.

With the cylindrical pipe type of precipitator described, about the same efficiency of cleaning was obtained for a number of materials, such as ashes, alumina and cement dusts, fine powdered clay, sand, and hot and cold smoke.

APPLICATIONS OF ELECTRICAL PRECIPITATION

A study of electrical precipitation processes and apparatus, applied to the cleaning of producer and blast furnace gases, is a field in itself of immense value to all interested in the steel industry. We must admit that proper methods of firing furnaces whether in power plants, mills, factories, or our homes, and either by hand or mechanical devices, will do a great deal to eliminate a large amount of our inexcusable smoke nuisance. However, there are many instances, where through limitations of furnace room space, equipment, etc., the furnace, fired by hand or by a stoker, is called upon to do a duty two or three times its normal rating. Under such conditions an electrical precipitation outfit might be of service either continually or at intervals, because it will precipitate the ash as well as the carbon particles.

The mechanical stoker, when properly used, eliminates very largely the carbon constituents of smoke by providing conditions of more perfect combustion but it gives no aid in eliminating the discharge of ashes from the stacks of our mills and factories, or the chimneys of our homes. This item is one greatly in favor of the electrical precipitating processes when cleanliness as well as recovery of finely divided particles is the issue.

Other methods which are non-electrical, and which have found more or less favor in removing suspended matter from gaseous and fluid bodies are: (a) Settling. (b) Centrifugal. (c) Washing. (d) Filtering.

SUMMARY

Electrical precipitation may be accounted for by considering the phenomena of ionization, and the laws of electrically charged bodies.

A molecule or group of molecules of any substance in the neutral state constitutes a material system in electrical equilibrium under the action of its own component electrical charges and these component electrical charges are capable in an electrical field of becoming detached from each other and from the matter with which they are associated.

Nature furnishes, on an enormous scale, an illustration of the first steps in the electrical precipitation processes as well as the actual precipitation of suspended matter itself.

The addition of an electron to a molecule or a group of molecules, or a particle of finite size, such as a dust or smoke particle, gives rise to a negatively charged ion or negative aggregate, which will be acted upon by an electrical field.

When an electron has been removed from a molecule, a group of molecules, or a material particle, it gives rise to a positive ion, or aggregate, which, while it exists, will travel toward the negative electrode.

The size of the charge on the negative or positive ion depends upon the number of electrons which have been added to or removed from the molecule, group of molecules, or material particle.

Raising the temperature of a gas increases its electrical conductivity; a larger number of ions of one or both kinds are present, and these gaseous ions, independent of the ions which may be formed from matter held in suspension, serve as conveyors of electricity.

Ions may become the centers about which aggregates will be formed; and from this view point we may account for the elevation of potentials by the forming of the aggregates, and the lowering of the potentials by splitting them up.

The principal ionizing agents are Roentgen and Becquerel rays, cathode and other rays, the electric field, heat, flames, ultra violet light, and chemical action. The most prominent of these ionizing agents in electrical precipitation are heat, the electric field, cathode rays, and chemical action.

When the temperature is sufficiently high to produce a red or white heat the velocity of some of the electrons becomes so great that they are able to escape from the metal, thus all hot and incandescent surfaces become the seat of a more or less intense stream of electrons and positive and negative ions.

This ionizing action of high temperatures has some effect on the migration velocities attained by the particles suspended in a gas, when they come into an electric field.

At low temperatures, gases, as well as their suspended matter may have little or no initial ionization, consequently the electrical conductivity is practically the same in either direction, and the suspended matter suffers little or no tendency to travel in the direction of the field.

For equal flow of current through gases, between two electrodes, the relative dimensions and positions of the electrodes and their polarities, will determine the potential under which the electric field must be established to give the most efficient precipitation.

The electrical precipitation of suspended solid or liquid particles of the non-conducting type, depends upon the intensity of the electric field, the quantity of gas to be treated and its temperature, the degree of initial ionization, and the type of corona discharge employed.

Very little if any difficulty is experienced in treating soft coal smoke if the temperature is low enough, and little or no deposit forms on the electrodes.

The use of the negative corona, while somewhat more difficult to maintain as judged by the coronal glow,—as the break down voltage is approached, is the most effective in precipitating particles in gaseous streams; and this is no doubt largely due to the high electronic and ionic velocities associated with this type of corona discharge, or electric discharge in general.

Any roughness or fine points on either of the electrodes of a precipitator tends to localize the discharge, and through such fields the particle-laden gaseous streams may pass without suffering precipitation of the suspended matter to the same extent as when the field is uniform.

Two important fields of application for electrical precipitation, provided the liabilities of danger are eliminated, are in connection with the cleaning of producer and blast furnace gases.

Electrical precipitation of soft coal smoke takes care of the ash as well as the carbon products.

Presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915.

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PRACTICAL APPLICATIONS OF ELECTRICAL PRECIPITATION AND PROGRESS OF THE RESEARCH CORPORATION

BY LINN BRADLEY

ABSTRACT OF PAPER

The technical and finanical progress made by the Research Corporation since its organization in 1912 is given, and several plants are described. Voltages, electrode spacings, power consumption, etc., are given for several installations. Mention is made of a number of improvements in the electrical apparatus and means for its control. Progress has been made towards standardization of apparatus for this work.

The paper is illustrated with reproductions from photographs of installations in various stages of operation. Curves and charts show the peculiar character of the circuit, the method of obtaining data to be used in designing treaters and of conducting tests. Alternating current of 250,000 volts, has been rectified and used for precipitating particles from gases. Fumes have been separated into fractions by means of temperature control and the electric processes.

A selected bibliography is included. The statement is made that within three years time the original capital of $10,100 has been paid back to the stockholders, and that a fund of over $150,000 has been accumulated from the corporation's work, to be used for scientific research.

IN CONNECTION with its development and administration of processes for removing from gases finely divided particles suspended therein, the Research Corporation has not only devoted considerable time and effort to consideration of the theories, but also has endeavored to successfully adapt them to a great variety of practical conditions, and to further strengthen and standardize the art. The history and theories of electrical precipitation have been described elsewhere[1] so it is not necessary to review them in this paper, and, moreover it is considered undesirable to do so because of the wide field to cover in recording the practical and commercial results already achieved.

The article by Dr. F. G. Cottrell, appearing in the annual report of the Secretary of the Smithsonian Institution for the year

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Manuscript of this paper was received February 8, 1915.

[1] See selected bibliography at end of this paper

1913 (only recently issued) gives an excellent outline of the work up to the time when it was submitted to the Public Printer. The present paper aims to broadly cover the work to date, including many things not given in previous articles.

The task of solving the numerous technical problems encountered has been so exacting of time and effort that heretofore it was considered best to refrain from publishing the results of the work and information as to our progress until the processes had been proved and the organization and the financial position of the corporation were advanced sufficiently to insure its commercial stability. The invitation to present a paper was finally accepted not only because it was believed that sufficient progress of a very definite nature had been made to warrant some statements, but also because it was believed that a report upon the progress and developments would prove to be interesting and valuable to members of this Institute.

The experimental work and the theoretical phases of electrical precipitation are replete with many interesting actual facts,—and also with apparent facts; and it is these latter which sometimes prove to be dangerous pitfalls. The difference between a successful and an unsuccessful installation often is very little from an electrical engineer's point of view, because the various other chemical and engineering features often are much more difficult of solution. Partly for these reasons we consider that the knowledge and experience gained through close connection with the wide range of practical work are among our greatest assets. Of course it is to be supposed that improvements and refinements will continue to be made from time to time, but it is hardly to be expected that radical departures from present fundamentals will be made in the near future. The valuable theories and formulas probably will follow the practical work, as is usual in this type of work.

Probably a great majority of the Institute's members are aware that high-potential electricity was employed for depositing or condensing particles suspended in gases many years ago, and that the accompanying phenomena could readily be demonstrated in the physicist's laboratory. Nevertheless it is a fact that use of the high-tension electric field for this purpose was not made commercial until in recent years, and that full credit is due Dr. F. G. Cottrell for having made this possible. In this connection the following remark is pertinent to a comparison of theory and industrial application. A well known chemical engineer, who invented some valuable processes and has made them commercially successful, has stated that after one has completely solved all of the problems which it is apparently possible to solve in a laboratory, and has obtained comprehensive patents and has thoroughly studied the conceivable theories, and therefore is liable to consider his work almost finished, he is rudely awakened when confronted with the cold, hard fact that fully 90 per cent of the real work remains to be done. It may not be possible to calculate the similar ratio between theory and practise in connection with electrical precipitation, but it is certain that the practical and commercial end has demanded an enormous amount of time and effort. If all the problems were of one type and they required only a knowledge of how to obtain a suitable electric field, the administration and development of the technical work in this particular case would be much less exacting in time and effort. The variety of problems and conditions, to which requests have been made to apply the processes, has been very extensive as one can readily observe from the information given in a later part of this paper. Nearly every problem which has been investigated by us has required that engineers of our staff not only fully understand our own processes but also be well acquainted with other details of the operations conducted at the plant in question.

The Research Corporation was organized in New York City early in the year 1912, one of its specific duties being to administer the patents assigned gratis to it by Dr. F. G. Cottrell and his associates, E. F. Heller, Edmund O'Neill, and H. E. Miller, these patents being in the field of electrical precipitation. The reader is referred to Dr. Cottrell's articles for the details of the gift and of the corporation's purposes and aims.[2] The total capital paid into the treasury was $10,100., out of which all expenses for organization, office equipment, salaries, etc., had to be paid until other income was obtained from the work. As the stockholders were prohibited from ever obtaining any profits from their holdings, it was considered unwise to administer the work along lines which might compel the Corporation to request more subscriptions to its stock. Also, and for similar reasons, our operations were so conducted that no financial obligations would accrue to either the stockholders or the directors. Therefore, one of the requirements of our early contracts was that the client had to pay all expenses incident to our work upon his problem, and in addition thereto had to pay to us certain stipulated sums of money for technical services. While this was not the most ideal arrangement, nevertheless it should be realized that the adoption of such policy made it possible to prove and stabilize the work without resorting to the further sale of shares of stock. This latter feature was especially desirable because the founders of the Corporation, and especially Dr. Cottrell, desired to prove and to emphasize the tact that a large sum of money was entirely unnecessary for starting and proving the work and making the Corporation a financial as well as a technical success. One thought was that the industries benefited by its work should contribute to the support of the altruistic movement. Results have proved the contentions and all the parties who assisted so earnestly and capably, as outlined herein, are entitled to thanks for their generous support.

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[2] See selected bibliography at end of this paper.

The technical situation of the electrical precipitation processes in March 1912 was about as follows:

A commercial installation was condensing sulphuric acid mist at the Selby Smelter in California,[3] this having then been in successful operation for at least two or three years. This installation was designed and superivsed by Dr. F. G. Cottrell assisted by H. A. Burns. It is in steady operation at the present time.

Another installation was made on lead roaster gases at the Selby Smelter, but it was not continued, due primarily to the physical condition of the precipitated material, and because the farmers still complained of the sulphur dioxide which, passing through the treaters as a gas, the processes were not expected to and of course did not remove.

Some experiments[4] had been made by Dr. Cottrell assisted by Mr. Burns at the Balaklala Smelter in Shasta County, California, and a large installation was subsequently made for treating all the gases passing in the main flue. This large installation removed from 80 per cent to 90 per cent of all solids, and, had it not been shut down pursuant to a court order obtained by the farmers and likewise based on the sulphur dioxide concentration in the stack gases, and abandoned before final testing and adjustments could be made, it is reasonable to expect that the percentage of solids removed by the processes could and would have been increased considerably. Recent experience with similar problems certainly warrants such a statement.

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[3] See selected bibliography at end of this paper.

[4] See selected bibliography at end of this paper.

They also installed a treater in a sulphuric acid plant a few miles north of Berkeley, California, which successfully collected all the sulphuric acid mist, but it was not kept in industrial use, because of the existence of certain commercial arrangements which concern sulphuric acid manufacture by the contact process. Mr. Burns superintended some experiments in a sulphuric acid plant at Bayonne, N. J., a few years ago, the object being to remove dust from hot burner gases. Experience with details of the processes were more limited then than now and the result was that the testing was discontinued before conclusive results were obtained. It may be of interest that recently we undertook this same problem at another plant and the results were successful and a commercial installation is now to be made. The difference between the results at the respective places was due more to mechanical features and control than to any inherent faults of the electrical precipitation processes, even as originally applied.

Dr. Cottrell and his associates also successfully employed high potential electricity for separating water from crude oil, when these ingredients were obtained from the California oil wells in an emulsified form, but as these patent rights are not a part of the Research Corporation's holdings, no further mention will be made of them in this paper.

Mr. Walter A. Schmidt[5] undertook to adopt the electrical precipitation processes to the existing conditions at the Portland Cement plant near Riverside California and early in 1912 had made excellent progress, having up to that time installed one complete treater unit for the gases from one rotary cement kiln. Ten units are now in continuous operation at that plant, collecting in the neighborhood of 100 tons of dust daily.

After experimental work had progressed satisfactorily at Riverside, and the Balaklala installation had ceased operating because of the sulphur dioxide controversy, Messrs. Howard and Rathbun started experiments with the electrical processes at the Garfield Smelter of the American Smelting & Refining Company, the immediate problem being to remove the solids from the gases coming from copper matte converters. These gases carry a considerable quantity of lead compounds together with other metal values. The principal object of the fume collection was to save the values. Mr. Barker succeeded Mr. Rathbun in this work, the latter having resigned to accept a position as Chief Electrician of a large smelter in British Columbia. When the Research Corporation was organized, the work at Garfield was still in the experimental stage. During the summer and fall of 1914, the large installation at Garfield was completed and the entire volume of converter gases is now being successfully treated, with a reported collection of over 95 per cent of the suspended matter. The Garfield installation is in the territory controlled by the Research Corporation.

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[5] See selected bibliography at end of this paper.

The above condensed record shows the extent to which the electrical precipitation processes had been developed when work was started in the eastern part of the United States by the Research Corporation. Naturally, it may be surmised that almost innumerable schemes were tried and that many elaborate and complex laboratory experiments were conducted prior to 1912 in connection with efforts to explain the apparent inconsistencies and to make the processes most widely applicable. It seems that in the earlier periods of scientific and complex technical work, it is the usual experience that a great amount of time and effort is devoted to very intricate and difficult methods, and that the simpler and more practical methods of accomplishing certain desired results are not adopted until a later period.

It is reasonable to expect that processes for this kind of work must operate simply and reliably if they are to succeed in the greatest variety of problems and to the highest degree. The induction motors of modern types represent a good model to be kept in mind when developing such a field, as they perhaps come nearest to being foolproof of any electrical apparatus now in general use. This goal may be too much to hope for electrical precipitation but it is well to strive for it. Our plans and efforts have been guided considerably by such model as we have striven to improve and standardize these processes.

It does seem strange at first thought that the electrical processes were first successfully used in a commercial way for the precipitation of sulphuric acid mist, which material had previously been, and even to this date is, one of the most difficult materials to collect by ordinary methods; but, happily, by the electrical processes, this material is handled with greater ease than most any other. This mist consists of extremely small drops of sulphuric acid, generally containing some free water.

The following brief statement is made at this point for the benefit of those who may not be so informed. To remove from gases either solid or liquid particles carried in suspension therein, the present method is to subject the gases and suspended particles to the action of a strong electric field maintained between so-called " collecting electrodes " and " discharge electrodes," the latter being insulated from the former and connected to a suitable source of high electric potential. Alternating current fails to give the kind of field most desired, therefore the polarity of the " discharge electrodes " generally is kept fixed, the current flowing between the electrodes through the gases being essentially unidirectional. This is accomplished in practise by stepping up single phase alternating current to a rated potential of say 100,000 volts, connecting the " discharge electrodes " to the high-potential terminals of the transformer in such a manner and for such time as to produce the most suitable discharge from the " discharge electrodes " and maintain the desired potential difference between the opposed electrodes. The high-potential alternating current is changed into high-potential direct current by means of suitable rectifiers. The gases are rapidly ionized and the suspended particles removed by the forces acting between the electrodes. Maintaining the " discharge electrodes " negative with respect to the "collecting electrodes" is the general rule. By use of apparatus designed by us, 250,000 volts a-c. has been successfully rectified and efforts are now under way to raise this figure to a much higher value. However, the difficulties encountered in handling such pressures are so many that these extreme potentials may not quickly come into general commercial use, in the immediate future at least.

The potential difference between electrodes up to 1912 seldom exceeded 50,000 r. m. s. volts. In some instances the potential gradient near the so-called " discharge electrodes " was very low and a brush discharge or corona was not readily obtained unless a pubescent surface was employed. This improvement in electrode surface is used at present in certain cases, but in most of the problems it is not considered particularly necessary. As the work developed, higher potentials were used and thus other fields were opened to the processes.

The electrical equipment must be of such design and construction as to be suitable for the peculiar type of circuit, and it should be compact, economical and foolproof and still allow and insure uninterrupted operation where desired. The transformers must be strongly built, but not too expensive. The treater proper, which contains the so-called "discharge electrodes" and "collecting electrodes," past which the gases travel, must be of such material and construction that corrosive gases, if present, cannot too quickly destroy it. It is good practise to design the treaters of ample proportions, easily accessible to the electrodes and insulators, and with due regard to conducting the gases into and out of it and to the location of flues, furnaces, stacks, buildings, etc. Under some circumstances it is desirable to treat the gases while traveling horizontally, while in others a vertical gas flow should be adopted. Sometimes special types of electrodes must be employed, but the variety of problems and conditions is so great that it is not considered desirable to endeavor to prescribe any general rules in this regard.

The treaters must be arranged so that the dust, fume or liquid may be readily removed after deposition. In some problems a leakage of air into the gas to be treated is not harmful, while in others, such as the burner gases in sulphuric acid manufacture, dilution is objectionable.

Suppose that the treater proper has been correctly designed, constructed and installed, and that the electrical equipment is suitable and in proper adjustment. It may be found that many and more difficult problems are yet to be solved; because a plant owner will not be satisfied unless the entire installation, of which the electrical apparatus and treater are but parts, operates properly; particularly, the furnaces or other source of fume or dust must continue to produce quality and quantity as before. Detrimental influences should not be introduced into any portion of the plant. Actual examples have been encountered which illustrate the points quite well. In one case the flues were designed and installed by the plant's own engineers in such a manner that the natural draft was somewhat interfered with. In order to justify their own work they declared that the electrical processes had made it impossible to operate the furnace as before; but the fact is that the processes had nothing to do with the results, as it was entirely a problem concerned with utilization of natural draft. In another case the processes were blamed on the ground that the collected product could not be conveyed by screw conveyors, although the plant's engineers admitted that they never had been able to convey similar material by that method. In the former case, we obtained our own gas data at the plant and then redesigned and changed the flues and stack, keeping the treater and processes as they were, and then were able to demonstrate to and convince their engineers that not only could their furnace be operated and the dust removed from the gases by the electrical processes simultaneously, but, moreover, the capacity of that particular furnace was increased so that it produced about 10 per cent more finished material than any other similar furnace they had, and also the quality of the product was even better than before. In the other case, the material was slightly modified in chemical composition by introducing more dust into the gases, and the result has been that the material is now being conveyed and the electrical processes are therefore considered successful, although the change was merely one of local conditions having no direct bearing upon the processes themselves.

As has been stated above, the difference between success and failure is sometimes very small, and yet some persons remain somewhat skeptical even after a "near-failure" has been converted into a success, because they are unable to see just how the seemingly unimportant (to them) changes could produce such a "magic" effect. One could relate some really amusing incidents in this connection. In one particular case, when it seemed to be impossible to satisfactorily collect the dust from certain gases by means of the processes, a number of things were tried in regular order, hoping that some of the schemes would bring a solution of the problem. It is interesting that the very changes that eventually insured success had previously been discarded as worthless in earlier work, owing to false assumptions as to some of the apparently minor details. Such experiences indicate the wisdom of weighing most carefully the effect of all local conditions when difficulties are encountered. For some time past, however, more rapid and sure progress is made, because it is much easier to detect the causes of the various troubles, and once known they are quite readily corrected.

A partial record of the results obtained since 1912 is given below.

The first problem undertaken since that time was to recover the valuable fumes from silver refinery gases at the Raritan Copper Works, Perth Amboy, N. J., after they had passed through a water scrubber which was supposed to recover practically all of the values. In this installation very corrosive gases were encountered. Many materials of construction were experimented with,—even ductile tungsten, which, at that time (1912), was not readily obtainable. The construction problem finally was solved by the use of heavy cast iron in parts and a mixture of lead and antimony for other parts. Insulation and natural draft troubles also were encountered but finally they were overcome with the result that the installation has already saved several thousand dollars worth of valuable fume. The power consumption is about 2.5 to 3 kw. and the voltage averages about 35,000. Recently we have installed some 12-inch and some 24-inch diameter lead pipes for additional treaters which are of very simple construction. These operate very successfully and mark a distinct advance over the old type treater in several respects. Lately there has been installed at this plant a 10-kv-a., 25-cycle single-phase 100,000-volt transformer, a 500-rev. per min. motor-generator set, and a large rectifier. With this equipment greater spacing between electrodes is possible and the operation is generally improved. Occasionally some of the deposited fume, which is a good conductor of electricity, drops between electrodes and draws a heavy arc. This used to cause the automatic circuit breaker to open and an auxiliary circuit to ring a bell and notify the attendant. An automatically operated mechanism was developed and installed thus overcoming this trouble and increasing the values recovered.

A small treater was installed or the Vulcan Detinning Company for removing hydrated tin chloride from a small quantity of gases, these being the exit from a chlorine detinning plant. The hydrochloric acid, free chlorine and tin chloride together constituted one of the worst fumes for human beings that we have yet encountered. The tin chloride and a portion of the acid and the chlorine were recovered but the final installation never was completed because the plant manager feared that water vapor might be drawn back through the treater and into the anhydrous gas lines, thus closing them and stopping operations due to a solid compound resulting from the reaction between the water and the anhydrous tin chloride. The original treater insulation was not fully satisfactory, although it permitted most successful operation if it was occasionally cleaned. A modified treater of simple construction was suggested whereby all the remaining difficulties could have been overcome, but it was not installed. The electrical equipment easily and completely precipitated the tin compounds for which it was installed, but for various commercial reasons the use of the processes was discontinued. With the present knowledge and the experience gained since then, the problem could be easily and cheaply solved even with the original electrical equipment. The problem of insulation at the point where the high-tension current entered the treater was really the most difficult to solve because of such fumes; the later designs overcame this.

During the time a treater was first operated by the Balbach Smelting & Refining Company, on the gases from cupel furnaces, the value of the material recovered did not warrant its continuous operation. It was believed that the losses were considerably greater than the actual collections indicated, so the treater was shut down and experiments thereafter were conducted upon a small scale, because of the greater ease of changing conditions with a small apparatus than with the large treater. One purpose was to obtain a close estimate of the total fume values being lost from the furnaces, as this would decide whether work would be continued. Results of operations to date are highly encouraging and success upon the final scale is assured. The volume of gas is about 10,000 cubic feet per minute.

Opinion was widely divided as to the probability of successfully adapting the processes to Waterside Station No. 2 of the New York Edison Company, the problem being to remove cinders from the boiler plant gases. Nevertheless, for various reasons, efforts were made and the following conclusions reached. There was not sufficient available space for treaters in the building to insure successfully treating all the gases, especially without imposing prohibitive restrictions upon the natural draft. Tests under ordinary conditions of installation showed that the cinders could be removed while moving at a velocity between 10 and 15 feet per second without using water and that they could be cleaned at a considerably higher gas velocity when water was used; but the consensus of opinion was that tests should be discontinued until better assurance of success in this problem might be obtained. Perhaps this same type of problem will be again undertaken at some future date, as the prospects of success are much brighter now than formerly.

Our tests at the plant of the Orford Copper Company, on a semi-commercial scale were successful. Various kinds of gases were treated and a large amount of data obtained which would be useful when the full scale apparatus was installed. The various flues, stacks, etc. were studied, plans and specifications for equipment to handle all the gases were prepared and submitted with our report. The values recoverable from the gases apparently would not be sufficient to warrant the heavy installation expense; therefore, before deciding to incur the financial risks incident to such a large installation, especially when only an alleged nuisance was involved, it was decided to await further developments. It is quite likely that the large installation eventually will be made at this plant.

At the plant of the Hooker-Electrochemical Company, a large volume of air, containing a small percentage of chlorine gas, is treated for the removal of the latter. Hydrated lime dust is used to assist in the removal, and a few tons per day of weak bleaching powder are collected. The volume of gas is about 30,000 cu. ft. per min., with a power consumption of from 3 to 5 kw. Weak bleaching powder, chlorine gas and hydrochloric acid are not conducive to a simple insulation problem, as can be readily imagined; nevertheless it was successfully handled, even for 50,000 volts. In this case our most difficult problems have not been concerned with the electrical processes specifically, but, on the contrary, have been to obtain a steady introduction of hydrated lime into the gas and at a given rate. Other mechanical problems were met and solved. Occasionally it has seemed odd that those concerned only with these electrical processes should have to devote any time and effort to extraneous matters, but unless they do, the electrical processes are liable to suffer condemnation; hence the assistant engineer in charge must not only solve his own problems but must also solve the other man's problems (although they may be only remotely connected) in order to have his own work accepted.

The gases from a hand-fired 80 h.p. boiler at the U. S. Bureau of Mines are treated for the elimination of black smoke when certain coals are being tested and it is not expedient to prevent the production of smoke. The removal of the carbon and other particles of the smoke is accomplished quite readily but the question of suitable disposal of the collected soot is still under consideration and some further tests are being made. As is to be expected, the results obtained thus far indicate that it is best to prevent formation of smoke whenever feasible, and not adopt methods for collecting it. But it should be noted that there are many places where, for local reasons or for immediate economy, it is best to install the electrical processes, as by them complete elimination of the smoke can be obtained readily. The treater contains twelve iron pipes 12 in. in diameter by 12 ft. long, through which the gases pass. The high-tension electrodes are placed vertically so as to subject the gases to the forces in the electric field throughout the entire length of the pipes. A pressure of about 50,000 volts is used, and the power consumption is approximately one kw. The exciting current of the transformer is considerably higher than that of later transformers, and the power factor is low in comparison with other and more recent installations.

Fig. 3 is reproduced from a photograph which shows the general arrangement of the treater.

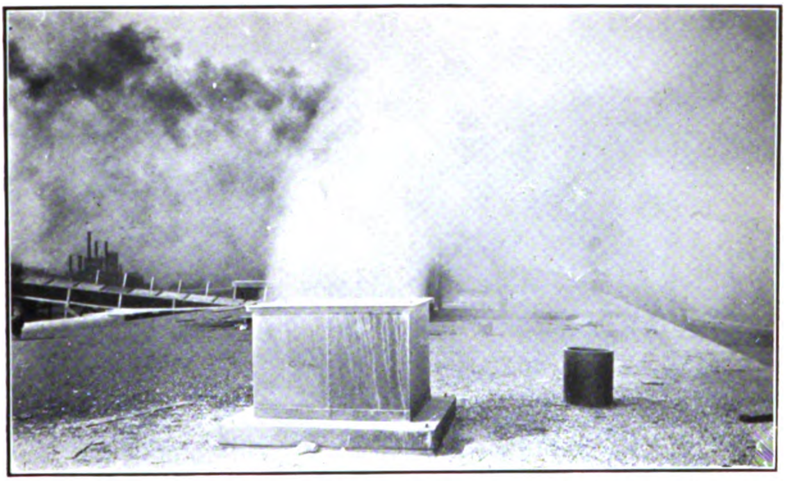
Figs. 4, 5, and 6 show the effect of the electric field upon the smoke, the first showing the effect when the electric circuit is open, and Fig. 5 shows conditions 30 seconds later. Fig. 6 plainly illustrates how the smoke began to show itself at the stack top when the current was stopped. Figs. 7 and 8 show the voltage off and voltage on. The results of the work to date may be summarized as follows: The smoke can be precipitated readily; the insulation problem is not now a difficult one. The treater can be constructed and operated within the limits of good practise with regard to corrosion; the power consumption is low; there need be no difficulty in operating with natural draft if there is sufficient room to build breachings, treaters and stacks. The apparatus can operate continuously, requiring but little attention; the most annoying question is what disposition shall be made of the collected material? It is expected that in the next few months something more definite can be stated regarding this latter feature. Mr. A. F. Meston has charge of the details of this installation.

Gases from sintering machines and roasters at Salida, Colorado were to be treated, but the tests made in the latter part of 1912, did not indicate that the values in the gases at the time was sufficient to warrant the expense of installation. The plant management had been endeavoring to reduce their lead losses to a minimum by close chemical control of the material fed to the furnaces. It is possible, however, that this plant may find that it is more desirable to use the electrical processes than to exercise such careful control over the charge. Recent developments have so reduced installation costs that the problem may be reconsidered, especially since the processes are now in successful use on similar gases at another lead smelter.

Tests were conducted on a semi-commercial scale at the Kings County Foundry with results showing that complete recovery of the fume was feasible. The gases come from cupola furnaces in which old tin cans and other metal scrap are reduced to a poor grade of iron which is made into sash weights. The fumes consist mostly of tin, lead and zinc oxides and the quantity per day is considerable. The cost of separating and refining the metals, when they are in the proportion as shown by analyses of the collected material, is such that the expense of the installation has not yet been incurred by the company which proposed to operate it, and therefore the scheme has remained dormant since the completion of our tests and submission of our report. When a process has been perfected for treating these fumes economically so that the tin, lead and zinc can bring something close to their market value, the field is a good one in which to build up another by-product industry. As these sash weight foundries are operated at present it would be necessary to install a fairly extensive system for cooling the gases down to a reasonable working temperature. Of course, such apparatus increases the cost and helps to make difficult the profitable collection of these fumes at the present time.

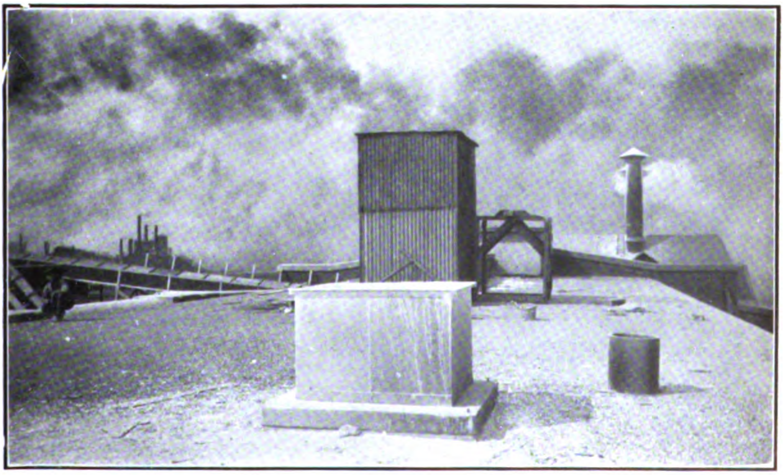
Elaborate tests upon gas volumes, composition, temperature, fume content, etc. were conducted for the Chase Rolling Mill Company in order to secure reliable data upon which to base designs for full scale commercial installations. The fume is mostly zinc oxide originating at the crucibles in which zinc and copper alloys are produced. Many tests were conducted with the electrical processes while the gas conditions were varied as to velocity, temperature, etc. The results were very gratifying, showing that the financial returns would pay well. Plans have been prepared for large commercial installations at the various locations and a contract for a portion of the installation has been awarded. Some very valuable data and information were obtained in the investigations at this plant and these will be useful in many other installations also. Early in the testing work at this plant such discouraging results were obtained that some of our own technical men considered it to be a hopeless task, and it was with great difficulty that they were induced to renew the work and carry it to so favorable a stage as it is now. The management of the plant kept its faith throughout the trying periods when tangible results seemed to be the exception, and its course is to be commended. Mr. P. E. Landolt had charge of the details of the work at this plant.

Prof. A. H. White has succeeded in cleaning the entire make of illuminating gas at the plant of the Ann Arbor Gas Company by means of the process, the installation requiring a very small



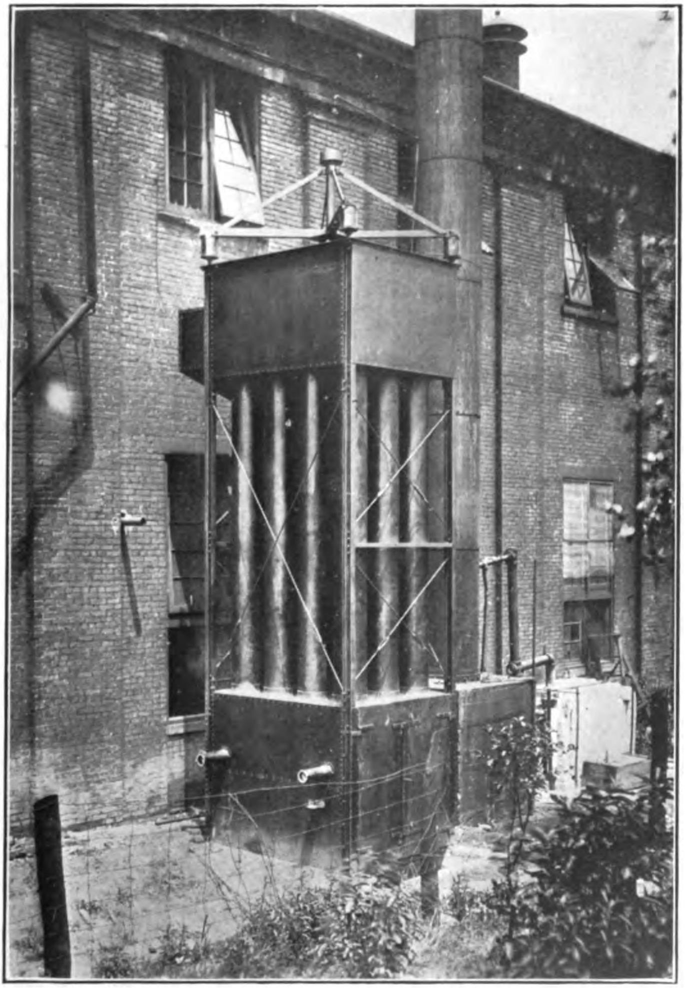
[BRADLEY]

FIG. 1—EXHAUST FLUE FROM THE TREATER AT THE HOOKER ELECTROCHEMICAL COMPANY'S PLANT AT NIAGARA FALLS, N. Y.—VOLTAGE OFF.



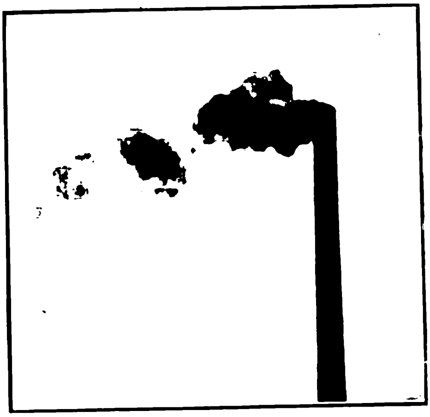
[BRADLEY]

FIG. 2—EXHAUST FLUE FROM THE TREATER AT THE HOOKER ELECTROCHEMICAL COMPANY'S PLANT AT NIAGARA FALLS, N. Y.—VOLTAGE APPLIED



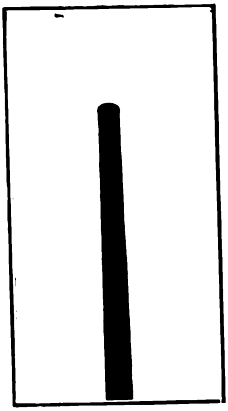
[BRADLEY]

FIG. 3—BUREAU OF MINES TREATER—PITTSBURGH, PENNSYLVANIA



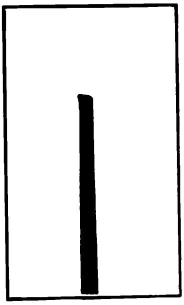
[BRADLEY]

FIG. 4—TOP OF STACK—BUREAU OF MINES TREATER, PITTSBURGH, PA.,—VOLTAGE OFF



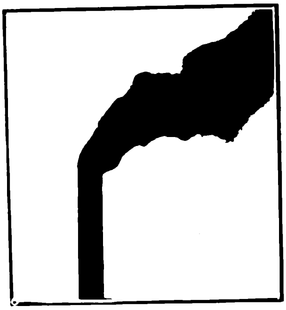
[BRADLEY]

FIG. 5—TOP OF STACK—BUREAU OF MINES TREATER, PITTSBURGH, PA., —THIRTY SECONDS AFTER APPLICATION OF VOLTAGE TO TREATER



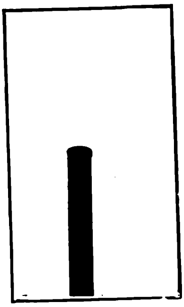
[BRADLEY]

FIG. 6— TOP OF STACK—BUREAU OF MINES TREATER, PITTSBURGH, PA.,—SEVERAL SECONDS AFTER VOLTAGE IS CUT OFF



[BRADLEY]

FIG. 7—TOP OF STACK—BUREAU OF MINES TREATER, PITTSBURGH, PA.,—VOLTAGE OFF



[BRADLEY]

FIG. 8 — TOP OF STACK—BUREAU OF MINES TREATER — PITTSBURGH, PA.—VOLTAGE ON

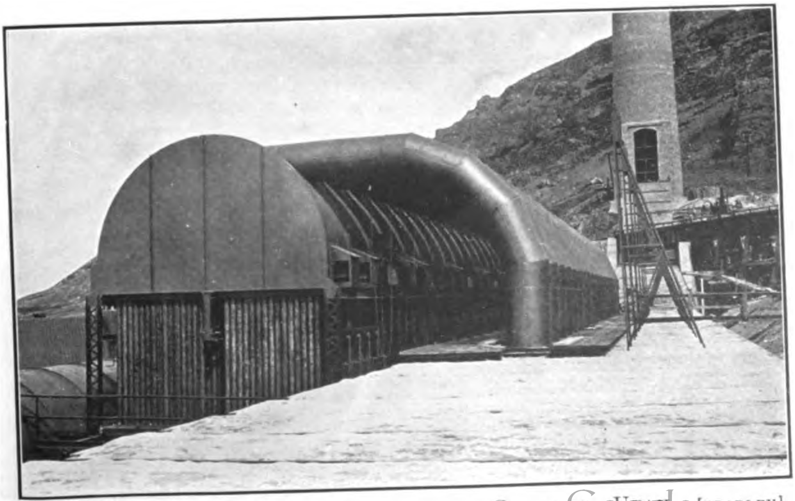


FIG. 9—GENERAL VIEW OF TREATER AT GARFIELD, UTAH [BRADLEY]

amount of power. The tar removal was practically complete. At times during the testing period the gas velocity past the electrodes was over 30 feet per second. The installation is very simple and compact, and judging from his reports, should warrant its rapid and general adoption as standard equipment for this purpose by gas manufacturers. Prof. White plans to push this development quite vigorously throughout the summer vacation. His work is described in the *American Gas Light Journal.*

An installation at Omaha, Nebraska for collecting sulphuric acid mist arising from so-called "parting kettles" in a silver refinery, practically identical with the Selby, California, installation was also very successful. Mr. H. A. Burns had charge of the details of this installation.

The installation at Garfield, Utah is fully described by Mr. W. H. Howard in the Bulletin of American Institute of Mining Engineers, August, 1914. It consists of seven units each of 360 five-in. pipes, 2520 in all. The volume of converter gases treated is approximately 200,000 cu. ft. per minute. The collected material is quite high in lead, and several carloads have already been shipped for refining. It is a large, well constructed installation and is reported operating very successfully, the collection being about 95 per cent of total solids. Semi-commercial tests also were conducted upon main flue gases, coming from blast furnaces, roasters and reverberatory furnaces. These tests likewise were successful and eventually these gases also may be treated by the processes.

The electrode spacing is 2½ in., the potential about 30,000 volts, and the power consumption approximately 50 kw. The building which contains the motor-generator sets, rectifiers, control apparatus and switchboard panels is one to be proud of. Mr. Howard was assisted by Mr. R. F. Barker to whom the details were delegated.

Fig. 9 gives a general view of the treater. It is divided into seven electrical and mechanical sections. The converter gases, mixed with more or less air, come from the converter building through a long steel balloon flue, drop considerable of the heavier particles throughout the length of the flue, then enter the bottom header, pass upward through the five in. pipes, into the upper header, then through the long radius pipes into the main flue which also carries gases from other parts of the smeltery. The illustration was made prior to actual connection of the flue to the new stack which is in the right background.

The semi-commercial treater used early in the testing work at Garfield was subsequently shipped to Murray, Utah, and tests were conducted at the lead smelter with excellent results. The smelter already was equipped with a large and expensive baghouse, and for this reason it was not necessary to immediately install the electrical processes. The analytical results showed nearly 100 per cent of the suspended particles of fume and acid removed in the electrical tests, thus proving the effectiveness of the processes.

Small scale tests were conducted on gases from sintering machines at Tooele, Utah, carrying large amounts of lead, elementary sulphur, etc., and upon gases from roasters, converters and blast furnaces. In all cases the results were satisfactory. Two large units are now in successful commercial operation on the sintering machine gases and it is planned to install several others on these gases as soon as possible, and later to install treaters on other flues at this plant as well. Each of the two units contains 48 pipes 12 in. in diameter by 15 ft. long, placed vertically. The electrode spacing is six in., the volume of gas treated is approximately 20,000 cu. ft. per min., the power consumption measured at the transformer at present is less than five kw., the recovery of fume, when the treaters are not overloaded by forcing the blowers at the sintering machines, is practically complete. The fume contains a fair percentage of elementary sulphur, which formerly wrought havoc with baghouse installations, especially when it exploded. The potential on the treater as indicated by transformer ratio and primary voltage, is around 70,000 volts. At this plant also some changes in the metallurgical operations have resulted in a considerable reduction of the values lost in the fumes, hence the electric processes are not called upon to recover as much as was being lost a year or so ago. Figs. 10 and 11 picture the small scale treater operating on these gases, and show the effect produced by the current. Mr. H. A. Burns has directed the detail work connected with the processes at this plant and he has been ably assisted by the smelting company's technical men.

Without having conducted any preliminary tests, a full scale treater was designed, erected and placed in operation for the Goldschmidt Detinning Company. The necessary alterations were very few and unimportant before a complete recovery of the tin compounds was being effected. The temperature of the gases sometimes reaches 800 deg. fahr. in the treater itself.

Occasionally the white fumes and black coal smoke alternate. One can then observe the successive layers of white and black fume precipitated upon the electrodes and by this aid can determine if the gas speed in all compartments of the treater is practically equal. There are nine-12-in. iron pipes, the voltage may range from 60,000 to 80,000, the power consumption from 600 to 1500 watts. Figs. 12 and 13 show the treater and some of the electrical equipment.

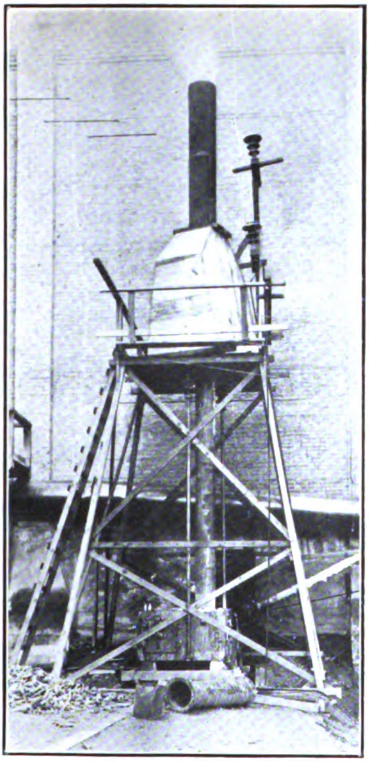
A treater was installed without conducting any preliminary test for the Milk Flour Company, as sufficient experience with the various influencing factors had been obtained to be able to make a successful installation without them. It is a very inexpensive outfit, used for collecting powdered milk, sugar, eggs, malt, grape fruit juice, etc. The powders are obtained from an evaporating plant wherein solutions, emulsions, etc., are deprived of their water by spraying the liquid into a current of hot air. The powder is removed from the gas before it cools sufficiently to allow deposition of the evaporated moisture. Excellent powdered organic materials are recovered in this manner at a small expense. Several very interesting and some fairly important facts were learned from this installation. A small electrical treater was subsequently installed for removing dust from the air before heating it, thus insuring a food product free from dirt specks. It may be of interest to note here that a party once inquired if we could remove bacteria from ordinary air by these processes, and whether the ozone and nitrogen oxides would render the air more healthful. Fig. 14 is a general view of the treater.

In response to a telegraphic request apparatus was shipped to the Washoe Smelter, Anaconda, Montana, to be used for removing valuable metals and acids from gases arising from a modified MacDougal roaster, in which the Anaconda tailings were being subjected to an oxychloridizing roast under the direction of their Mr. Laist. (Bulletin of A. I. M. E., August 1914). The gases at that time were being passed through a scrubbing tower without obtaining a complete recovery of the values. The electric apparatus and treater were quickly erected and tried out but at first with what was apparently unsatisfactory results. As similar phenomena had been encountered elsewhere it was possible to soon show that the cloud emerging from the treater was due to moisture being condensed from the gaseous to the liquid condition upon the gases mixing with cold air, resulting in a condition of supersaturation for the temperature existing after admixture of the gases. It was also noted that if the furnace fires were poked so as to produce black smoke, no black could be discerned in the cloud above the treater when the electric field was on, but this was plainly visible when the current was turned off;—the difference between the white cloud (current on) and the dark gray cloud (current off) being very pronounced. This was a good indication that all solids were being collected and that by a study of certain meteorological tables the proper explanation might be had. The temperature of the gases going to the treater was then so reduced that no cloud would result after the gases had passed through the treater. The results then showed a complete clean-up when the current was on and a dense white cloud above the treater when it was off. Some photographs were taken to show the remarkable effect and also the suddenness with which the electricity produced it. Some very good moving pictures of these fogs or clouds and their elimination were made at the time. Twelve-in. diameter lead pipes, 20-in. diameter wood stave pipe, and 24-in. diameter stoneware pipes were tested and all proved successful. It was interesting to view the tops of the pipes while in operation. One could see an absolutely clean gas over the cross section, except at a short distance from the pipe on which the cold liquid was deposited. One readily could observe how the fog was produced in a manner similar to a cloud formation when exhaust steam leaves a locomotive stack on a cold and humid day. The name " tea-kettle-effect " has been suggested for lack of a more appropriate and shorter term.

Examples of this effect have frequently been noted during tests elsewhere. The amount of "mist" formed after the gases were discharged from the treater varied with the temperature and humidity of the outside air. A typical calculation of such a condition will illustrate this point:

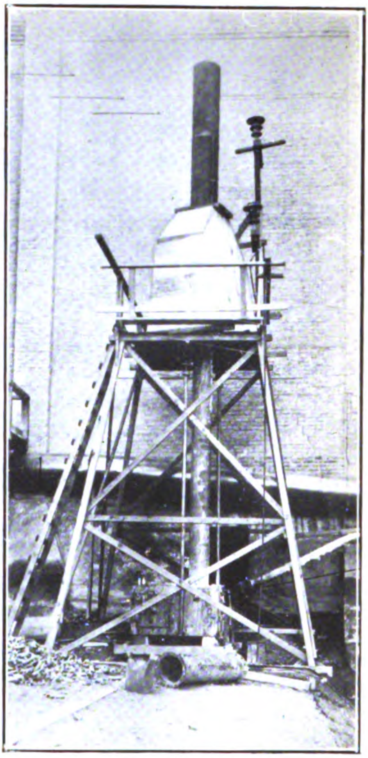
In a test treater handling 1800 cu. ft. of air per min., at a temperature of 152 deg. fahr., or 117 lb. of gas per minute, the air is saturated at 152 deg. fahr. (standard barometer) and carries 0.224 lb. of moisture in the vapor form per pound of air, or a total of 26.2 lb. of moisture per minute.

Assuming an outside air temperature of 42 deg. fahr. and 60 per cent saturation, and a sudden cooling of the discharged air to 52 deg. fahr. by mixing with the outside air, the heat transfer is as shown by the following equation:



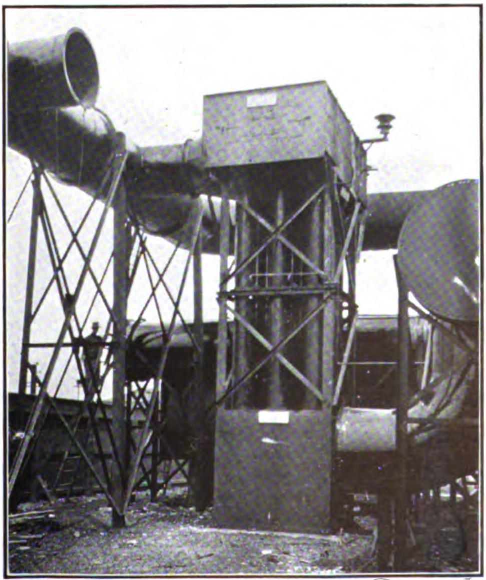
[BRADLEY]

FIG. 10—EXPERIMENTAL TREATER AT TOOELE—VOLTAGE OFF



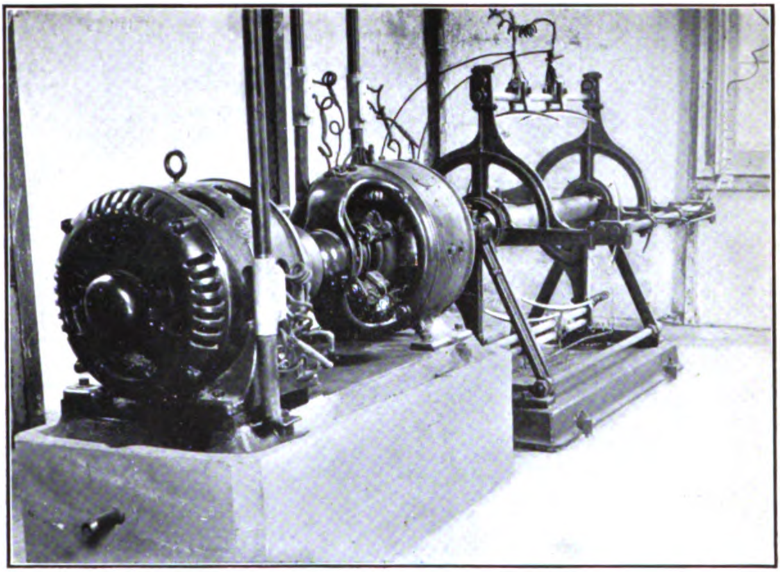
[BRADLEY]

FIG. 11—EXPERIMENTAL TREATER AT TOOELE—VOLTAGE ON



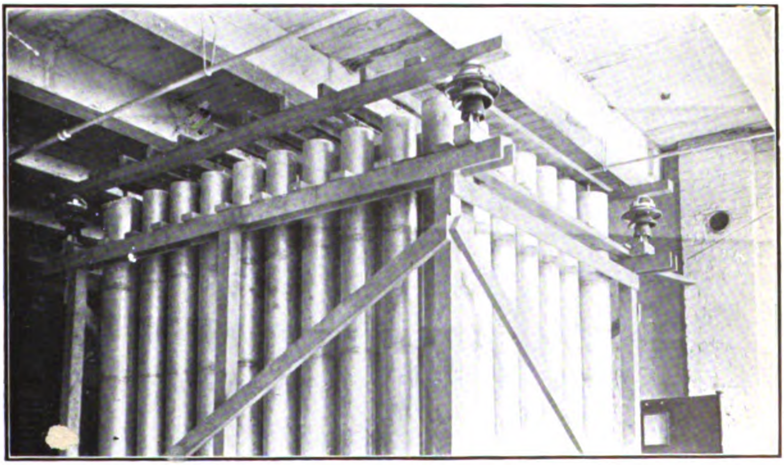
[BRADLEY]

FIG. 12—TREATER FOR GOLDSCHMIDT DETINNING COMPANY



[BRADLEY]

FIG. 13—PORTION OF THE ELECTRICAL EQUIPMENT FOR GOLDSCHMIDT DETINNING COMPANY



[BRADLEY]

FIG. 14—GENERAL VIEW OF TREATER FOR MILK FLOUR COMPANY (LOCATED IN A LOFT BUILDING)

$(117) \times (0.24) \times (152° - 52°) + (26.2) \times (0.46) \times (152° - 52°) = (X) \times (0.24) \times (52° - 42°)$

Where the specific heat of the air = 0.24

the specific heat of the water vapor = 0.46

X = lb. outside air per minute necessary to be mixed with the discharged air (neglecting radiation) to effect the cooling to 52 deg. fahr. and equals 1670 lb.

Then the amount of moisture per lb. mixed discharged and outside air is—

$$\frac{1670 \times 0.0056 \times 0.6 + 26.2}{1670 + 117} = 0.0179 \text{ lb.}$$

But the saturation point of air at 52 deg. fahr. = 0.008 lb. moisture per lb. air, so a "mist" or "fog" will form just above the top of the pipes.

This "fogging out" has been encountered repeatedly in practise. When tests are made during the winter season, a visible "mist" is formed after the gases are discharged from the treater, when warm saturated gases are discharged from treaters. During the periods of dry and warmer weather, the "fogging out" is greatly decreased.

In other cases, where the temperature of the discharged air, saturated with moisture, is only a few degrees above that of the outside air, no mist or fog is produced. It is possible to predict from calculations made in a similar manner whether or not a mist or fog will be produced under any given conditions.

It is further possible to show by calculations whether mixing two or more gases, varying in temperature and in percentage of saturation, in given proportions prior to passing through the treater, will avoid this formation of a mist or fog, when the discharged gases mix with the outside air.

The processes were for some time thereafter used in the tests at Anaconda to check up the furnace losses, as they could be depended on to collect nearly everything that escaped from it, and plans were being prepared for a large installation at the proposed leaching plant, but the later improvements in roasting and leaching made it unnecessary to add salt to the roaster and this in turn reduced the losses to such an extent that it was considered unnecessary to recover the values.

Immediately after the leaching plant tests had been concluded an installation of the processes was made at the Arsenic

Plant where flue dust is roasted to remove the arsenic from the metal values, and then the concentrated arsenic is recovered and refined. The plan was to separate the mechanically carried impurities from the gases at a high temperature, next cool the gases so as to condense the pure arsenic, and then recover it directly, thus saving a second refining.

This was the first really serious effort made to use electrical precipitation as an adjunct in fractionating components of fume, although some previous attempts had been made at Perth Amboy, N. J. in our work there on the silver refinery fumes. The results at the Arsenic Plant showed conclusively that it was a feasible method and after sufficient data had been obtained, a commercial installation was designed and started but construction work was suspended on account of the situation resulting from the European war and this installation has therefore not yet been completed; although reports state that it is now going forward.

Messrs. Elton, Dunn,[6] Kellogg and Mitchell have been handling the work at this plant during the latter period. They have also tested the processes on a semi-commercial scale on the gases from the blast furnaces, converters and roasters, and have obtained satisfactory results. They have even exceeded in size the three ft. pipe originally installed at the Arsenic Plant, by using an iron pipe four ft. in diameter as the collecting electrode, and a 250,000-volt transformer and mechanical rectifier to correspond. This latter is quite inexpensive although it is subjected to such enormous electric stress.

Treating the enormous volume of gases in the main flue at Anaconda presents several problems. In addition to magnitude there are the numerous problems connected with the handling of the fumes and dust and of their metallurgical treatment, so that it will be some months at least before any very definite progress can be reported. However, the results thus far obtained were so encouraging that the smelting company purchased a license for the use of the processes throughout their plants at Tooele, Great Falls and Anaconda, paid a large cash sum and now they are in position to make rapid progress with their installations. The Research Corporation still has a financial interest in certain elements of the fume which are to be collected when the processes have been installed. Figs. 15 and 16 show the experimental leaching plant at Anaconda and the electric

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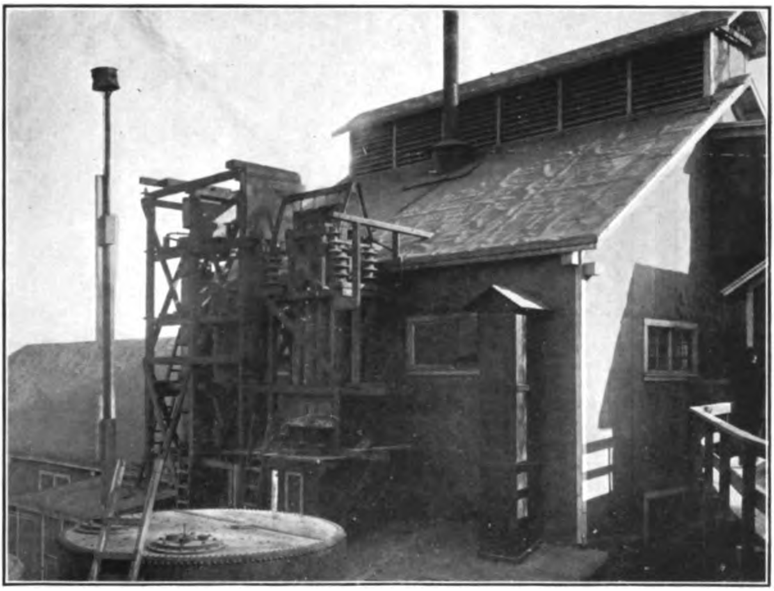
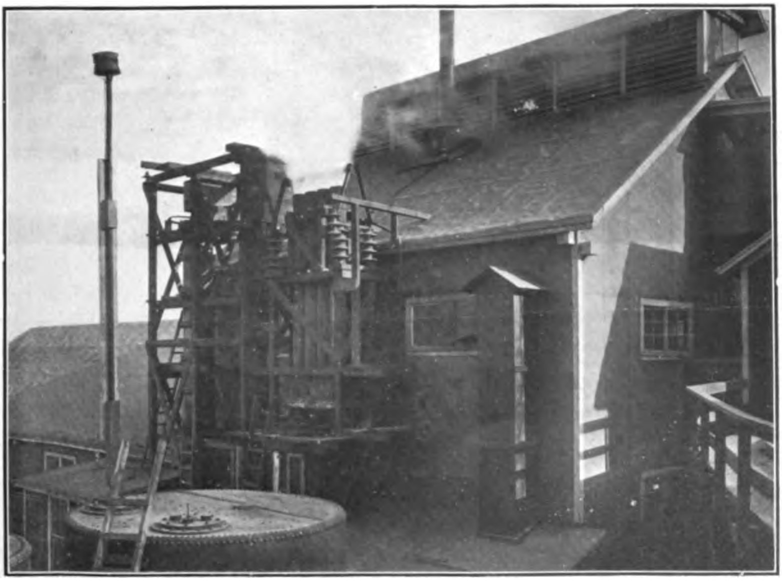
[6] See selected bibliography.



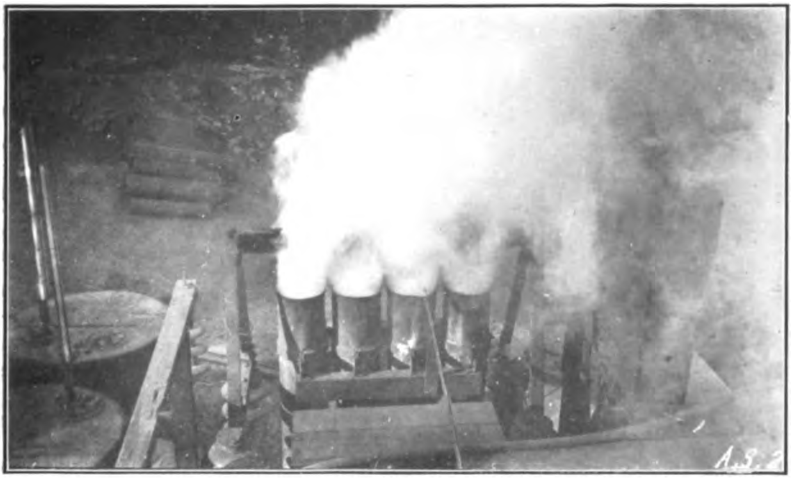
[BRADLEY]

FIG. 15—EIGHTY-TON LEACHING PLANT ELECTRICAL FUME PRECIPITATOR CURRENT ON



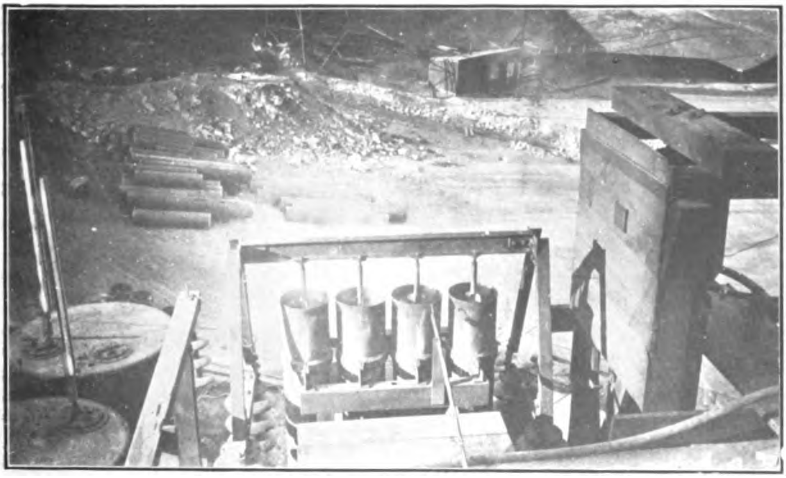
[BRADLEY]

FIG. 16—EIGHTY-TON LEACHING PLANT ELECTRICAL FUME PRECIPITATOR CURRENT OFF



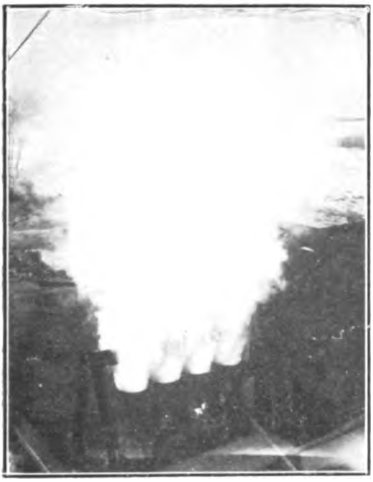
[BRADLEY]

FIG. 17—ANACONDA COPPER MINING COMPANY—TREATER AT EXPERIMENTAL LEACHING PLANT—VOLTAGE OFF



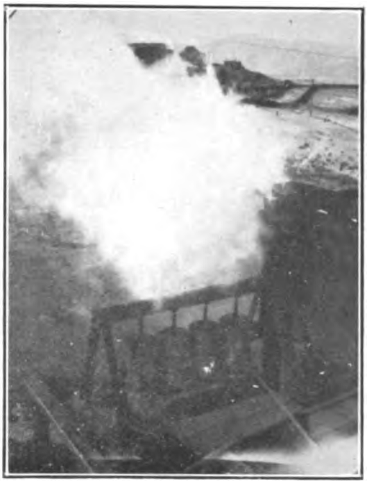
[BRADLEY]

FIG. 18—ANACONDA COPPER MINING COMPANY—TREATER AT EXPERIMENTAL LEACHING PLANT—VOLTAGE ON



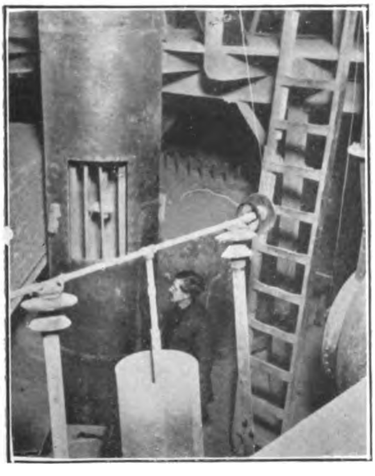
[BRADLEY]

Fig. 19—Anaconda Copper Mining Company Test Treater—Voltage Off



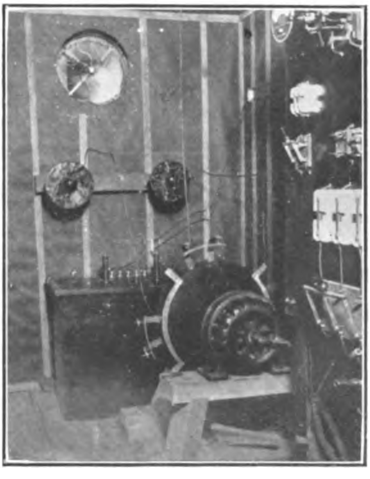
[BRADLEY]

Fig. 20 — Anaconda Copper Mining Company Test Treater—Immediately After the Application of Voltage—Good Example of the Rapid Change between Fumes and Clear Gas



[BRADLEY]

Fig. 21—Experimental Treaters at Arsenic Plant—Anaconda Copper Mining Company



[BRADLEY]

Fig. 22—Electrical Equipment at Arsenic Plant, Anaconda Copper Mining Company

treaters under various conditions of operation. Figs. 17 and 18 show how completely the fume is precipitated by the electric processes, the views showing respectively the " voltage on" and " voltage off" effects. The fume contained among other things, hydrochloric acid, sulphuric acid, dissolved sulphur dioxide, carbon, compounds of copper, silver, iron and arsenic. Figs. 19 and 20 show the rapidity with which the processes act. In the latter a clear space is visible between the tops of the pipes and the cloud of fume above, the film having been exposed very quickly after the current was thrown on. Although this fume is an excellent conductor, no difficulty was had with the insulation. A potential of 63,000 volts (as calculated from transformer ratio and primary voltage) was maintained on the treater.

Fig. 21 shows various features of the first installation at the Arsenic Plant, the hot gases being treated in the three ft. iron pipe to remove the solids, and the smaller and shorter pipe being used to precipitate a fair sample of the arsenic condensed out of the gases when cooled by admission of room air. The first test gave a precipitate in the second treater carrying 99.4 per cent arsenic trioxide. A portion of the impurity was due to volatile compounds from the wood used for fuel. Coke fuel in place of wood gave arsenic of a higher purity, sometimes reaching 99.9 As_2O_3. The electrical equipment is shown in Fig. 22.

At Catasauqua, Pa., is an installation for collecting potash salts volatilized from feldspar. This is operating successfully although the volume of gas being treated is greater than was specified by the owner's engineers. This undoubtedly is the first commercial installation in the United States built primarily for the production of potash salts, the residue being the by-product. At present the scheme as a whole is still in the experimental stage, but the collection of the salts by the electrical processes is proved. Mr. J. C. Hale has charge of the details of this work. The treater was designed for 12,000 cu. ft. per min., but it handles as high as 18,000 cu. ft. per min. at times. There are 40 pipes 14 in. in diameter by 12 ft. long, the electrode spacing being seven in. The temperature of the gases ranges from 500 deg. fahr. to 1000 deg. fahr. A potential of about 70,000 volts (calculated as mentioned above) is maintained on the treater, low tension alternating voltage about 190, and amperes 20 to 25. The power factor varies between 70 and 80 per cent when operating on the hot gases and fume. This same treater has been tested with only ordinary air in it, and at that time it was easy to furnish even more than 50 amperes to the transformer without any arcing in the treater. This is a good example of a difference in electrical conditions due to a change in the gas characteristics.

At this point it may be interesting to review some radical differences which we have observed due to certain predetermined changes in the gases, although the treater and electrical apparatus were the same in all tests.

Transformer voltage low-tension	Transformer voltage high-tension (by ratio)	Watts input to transformer	Milamperes line to treater (d-c.)
190	26,000	100	1.0
190	26,000	180	4.0
190	26,000	740	19.0
235	32,000	930	18.0
235	32,000	1600	35.0

In neither of the above tests was the potential raised to point of spark-over, but the following figures taken from another set of tests, show plainly the difference in the amount of current which can be passed in a given treater and the apparent potential reached just before spark over occurred. The only factor changed was that in the latter case the gas was slightly modified or conditioned.

Readings taken at voltage just under the sparking potential:

Voltage h. t. by ratio	Milamperes h. t. d-c.	
61,000	3.25	Gases unconditioned
80,000	10.5	Gases conditioned

It will thus be seen that it is difficult, if not impossible, to predict what the power consumption and voltage may be for a specified gas until actual tests have been made. The considerable variety of gas conditions already encountered has made it possible to divide gases into classes. Furthermore, methods have been developed whereby a close approximation of the required power and voltage may be obtained from the results of small scale tests.

With a large treater containing many electrodes the effect of the corona load upon the transformer and source of e.m.f. is different from an ordinary resistance load, due to the fact that above a certain point the current flowing through the gas between the electrodes increases more rapidly with a given rise in potential than would be the case if the electrodes were shunted by an ordinary high-resistance metallic conductor. For these and other reasons it is best to employ certain potentials and electrode arrangements for some gases and others for gases having other characteristics. Also the mechanical handling of the collected material must be duly considered when designing a treater.

Other problems upon which tests have been made with the processes are mentioned below. The most recent final installation was made in Worcester, Mass. at the North Works of the American Steel & Wire Company for collecting volatilized hydrochloric acid, thus mitigating or eliminating a nuisance and preventing further damage to surrounding vegetation. The wire company's own tests were so successful that it waived all requirements and asked that an invoice be rendered at once so they could make prompt payment and close up the account. No experimenting was required on this installation thus testifying to the thoroughness with which the preliminary survey was made before designing the apparatus. The exit gases are so free from acid that it is almost impossible to detect a trace of it even by delicate chemical methods. Table I gives the results of some tests on this installation conducted by the engineers of the American Steel & Wire Co. The treater is made of materials which resist corrosion.

In Cleveland, Ohio, at a sulphuric acid plant the gases come from an M. & H. kiln in which very finely divided zinc sulphides are roasted. The sulphurous gases are to be freed from the suspended particles and then delivered to a Glover tower of a lead-chamber sulphuric acid plant. The gases are to be treated at a temperature of about 800 deg. fahr. to 1000 deg. fahr. The gases contain some free sulphuric acid which tends to complicate the insulation problem. However, our semi-commercial tests at this plant showed that the problems could be solved, and pointed the way.

Designs of several types of treaters were prepared and at a recent conference one design of a horizontal treater was decided upon and it is to be installed at once. There are to be three sections, any two of which will clean the gases. Thus one section may be repaired when necessary. In this problem it is necessary to conserve the sensible heat of the gases and to avoid their dilution with air as this would materially affect the subsequent chemical operations. Mr. P. E. Landolt supervised the details of this work.

TABLE I

COTTRELL TREATER TEST—NORTH WORKS

Date	Water consumption		Per cent hydrochloric acid discharge water	Lb. acid per hr. precipitated.	Indicated voltage at rectifier.	Temp. of Outside air.	Humidity	Barometer	Kw. input motor-gen.	Kw. input fan motor	Total kw. input motor gen. and fan
	Cu. ft. per hr.	Lb.									
					volts.	deg. fahr.					
1 2:30 p.m. to 3:30 p.m. Dec. 21	31.5	1969	0.455	8.959	50,000	28	66	29.2" Hg.	2.24	0.90	3.14
2 4:00 p.m. to 5:00 p.m. Dec. 21	49.8	3113	.462	14.382	62,500	31	66	29.2" Hg.	2.91	0.90	3.81
3 9:50 a.m. to 10:50 a.m. Dec. 22	40.2	2513	0.113	2.840	50,000	27	69	29.4" Hg.	2.24	0.90	3.14
4 10:55 a.m. to 11:55 a.m. Dec. 22	42.7	2669	0.152	4.057	62,500	28	69	29.4" Hg.	2.91	0.90	3.81
5 2:45 p.m. to 3:45 p.m. Dec. 22	41.5	2594	0.138	3.580	45,000	28	69	29.3" Hg.	1.57	0.90	2.47

An installation for collecting sulphuric acid mist coming from a roasting furnace is under construction for the Standard Essence Company, and since it is so similar to other sulphuric acid mist problems, no difficult features are anticipated.

The problem has been surveyed for the Duquesne Reduction

Company; gas data as to volumes, temperatures, draft power, etc. was obtained; the volume of gas to be treated is about 11,000 cu. ft. per min. at a temperature of 600 deg. fahr., tests with electrical equipment showed the probable amount of dust obtainable and indicated how a large treater would operate. Contracts have been let for the full scale installation and work is being pushed as rapidly as possible. The dust and fume contain tin, lead and zinc oxides, from waste-metals. The probable values are so large that an excellent profit is expected. The first treater will contain 48 pipes 12 in. in diameter. Messrs. A. F. Meston and H. D. Egbert handled these investigations.

Similar data to that mentioned above has been obtained at a waste-metals plant of the National Lead Company. The probable recovery of values strongly warrants the immediate installation of the processes and advices to that effect have recently been received. The electrical process tests were highly satisfactory, and enabled one to obtain a dependable opinion as to the values now being lost, practically all of which can be collected readily. Mr. C. I. Weir had charge of this problem. The outcome of the investigations and tests is very gratifying, especially when it is known that some of their employees declared that their losses were only nominal.

Owing to various reasons beyond our control, tests of the electrical processes for the cleaning of iron blast furnace gases at the Bethlehem Steel Company were delayed. Arrangements now are being pushed so as to commence tests on a fairly large scale at the earliest possible date. It should be feasible to employ the processes either for cleaning these gases for stoves and boilers, conserving the sensible heat contained in the gases when they come from the furnace top, or for gas engine purposes, having cooled the gases previously. Perhaps both schemes will be tested at Bethlehem's plant, although the dry and hot gases will be handled first. The results are expected to have a very important influence in this field.

Arrangements have been made and a license sold to the Baltimore Copper, Smelting & Rolling Company for installations of the processes to collect sulphuric acid mist, under conditions similar to those at the Selby and Omaha plants, and for collection of valuable fumes from the silver refinery, similar to that of the Raritan Copper Works. Such excellent results had previously been had with these two types of problems and success was so apparent that the company purchased a license for a cash sum, in lieu of royalties.

At Maurer, N. J. also, the American Smelting & Refining Company paid a cash sum for rights to use the processes on a limited amount of mixed gases in the arsenic plant, but it is not intended that refined arsenic will be made by using the processes as described for the Anaconda plant. Electrical tests are now in progress and already the indications augur well for success. The mixed gases are apparently more easily treated at high velocities than their sintering machine gases alone. A program of tests is being carried out for the purpose of determining upon the best design and arrangement of the installation.

The plants mentioned above give an excellent idea of the progress which has thus far been made and should convince one that there has been an enormous amount of study and energy devoted to this work considering the age and policy of the organization. Nearly any one of the problems outlined has presented sufficient detail to command serious effort for months. The fact that it was not possible owing to a small treasury, to engage a large force of high-salaried engineers, has made progress perhaps even more difficult than if the organization had been more generously endowed financially. Now that the work has been proved and a fairly large balance is in the treasury, it is the intention to engage more technical assistants, and they will be selected to fill a certain place in the organization. Since it is not possible to have any one who is an expert in all lines of industry, experienced men in the various fields will be selected and charged with the development of that particular field for which he is best qualified. This leads up to the creation of departments for the proper development of the work and already steps have been taken in this direction.

In addition to the plants and problems mentioned above, it is also of interest to note that we have under consideration the following problems, upon which varying amounts of progress have already been made: These include the collection of

Aluminum oxide
Powdered starch
Powdered sugar
Powdered coal
Tin oxide for enamel
Powdered sulphur
Potash from burning of molasses
Potash from cotton seed hulls

Black smoke from round houses and other places
Fertilizer dusts
Zinc sulphides
Zinc oxides
Powdered borax
Fumes and dust from calcium carbide furnaces
Dust from rotary lime kilns
Dust from pyrite burners in sulphuric acid plants
Gold and silver from jewellers' sweepings
Fumes from linseed oil boiling kettles in varnish works
Powdered alundum
Ammonium chloride
Nitric acid, etc.

Inquiries have been recieved on many other problems but the above statements show that the electrical processes are applicable to a great variety of materials and conditions, especially when it is also considered that the range of operating temperatures is from a point at least as low as zero cent. to at least as high as 600 deg. cent., and at all temperatures between these two limits. Materials can be selected for each specific problem which will withstand the local conditions as regards temperature, corrosion, mechanical strength, expense, etc.

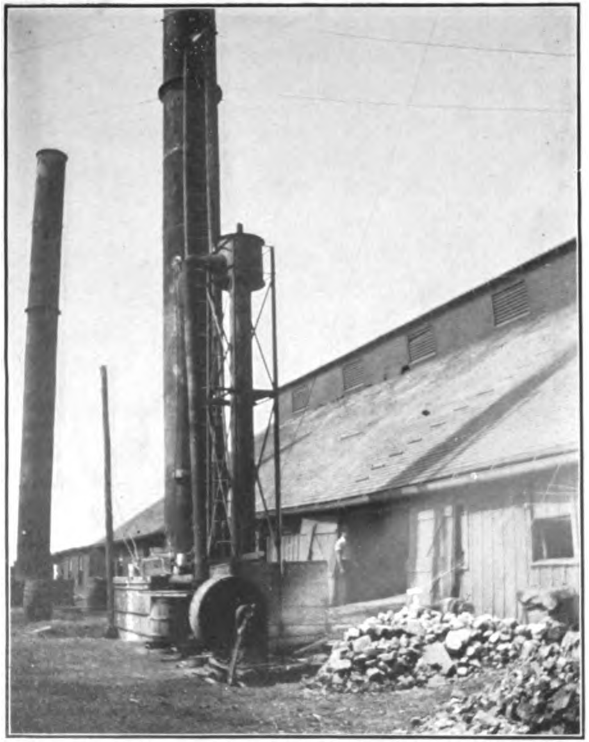
In addition to collection of materials, because of nuisance or of value of the suspended matter, it is worth noting that the processes are useful as adjuncts to other manufacturing processes or methods, either for improving operations or reducing expense. Both the lead-chamber process and the contact processes of producing sulphuric acid have several places in which the electrical processes should be valuable. The use of the electrical processes in conjunction with ventilation of the railroad tunnels in Baltimore is also under consideration and they may be installed there unless electrification of the railroads is decided upon, in which event, of course, there will be no smoke to precipitate. Furthermore, since it is so easy to remove dust from air by these processes, they may be useful in connection with the ever-present problem of suitably ventilating subways.

It should be apparent that contact with such a variety of actual industrial problems as has been mentioned would furnish an impetus to improving and simplifying treaters and the electrical apparatus, and to call forth a goodly number of patentable discoveries. While this is true, yet the policy has been not to overlook those mechanical and other operating features which would insure reliability of operation primarily and reduce cost of installation, maintenance and operation, as well as to make the processes as nearly automatic in operation as possible. Efforts along these lines were also accompanied by efforts toward standardization of types and sizes of treaters, of electrical equipment including switchboard panels, and to adopting schemes or plans that would facilitate and expedite the collection of data, conducting of experimental tests, and, finally, the completion of commercially and technically satisfactory installations.

The use of sphere spark gaps for the measurement of peak voltages between the discharge and grounded electrodes, and in other parts of the circuit has led to a better understanding of occurring electric phenomena. For these measurements a convenient portable sphere spark gap, as shown in Fig. 24 has been developed. Additional data on electric phenomena have been obtained by the study of the effect, under various conditions, of especially designed inductances placed in the high tension circuit. Methods have been devised whereby it is possible to predict quite closely the power required for the treatment of a specified quantity of a given gas. The power required for treaters is sufficiently low as not to be prohibitive in practically all cases where it is desirable to remove fine particles from gases. Power factors above 80 per cent are commonly found in the supply circuits. Actual power consumptions of installations now in operation will be found in the descriptions of some of the various plants given above. "Laboratory instruments" are in general too delicate for use in the field and "standard apparatus" often has failed to give satisfactory results until modified to suit the special requirements.

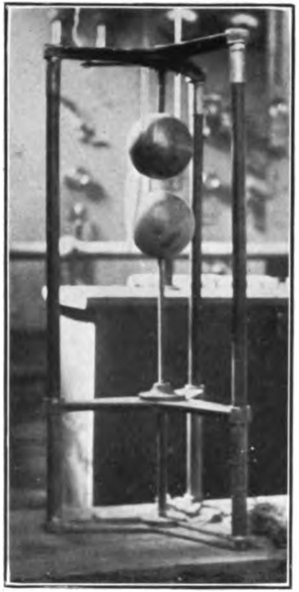
Improvements have been made in rectifiers and the method of using them. Some are now being operated commercially at 750 rev. per min., which speed presents some advantages over the former speed of 1800 rev. per min.

Transformer designs have been evolved which give apparatus very suitable for our work. Their reliability has been improved and the cost and time of delivery have been materially reduced. Apparatus has been developed to automatically restore normal operation after a temporary short circuit in the treater due to conductive precipitated material falling between the opposed electrodes, or to similar temporary overloads resulting from



[BRADLEY]

FIG. 23—TYPICAL EXPERIMENTAL TREATER INSTALLATION



[BRADLEY]

FIG. 24 — PORTABLE SPHERE SPARK GAP—RESEARCH CORPORATION DESIGN

unusual conditions. Improvements have been made in the manner of introducing the high potential line into the treater and along with these, improved methods of supporting and insulating the discharge electrodes have been developed. Durable discharge electrodes have been developed, thus overcoming the reasonable objections to the use of small wires in corrosive gases.

The typical curve shown in Fig. 25 gives the relationship between the high-tension direct current flowing into the treater and the high-tension voltage impressed upon it, the latter being shown on the curve sheet as the alternating potential delivered to the rectifier from the transformer and calculated from the measured low-tension voltage and the transformer ratio. Under certain conditions it would be preferable to measure the effective high-tension voltage maintained between the treater electrodes by means of a suitable voltmeter. In general, however, the voltage as indicated by the ratio method is sufficiently accurate for field work. The lower portion of the curve shows the uniform increase in the current with the voltage, due chiefly to insulator leakage. The upper portion of the curve shows the more rapid increase in the current as the voltage is raised above

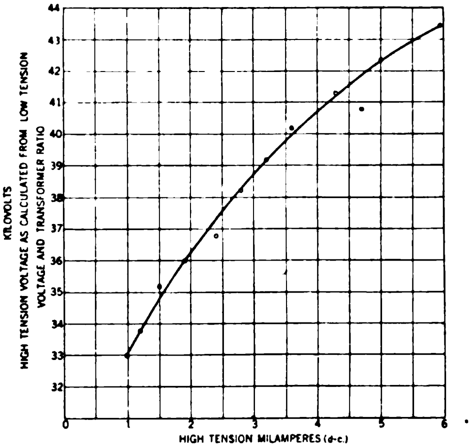


FIG. 25—CURVE SHOWING RATIO OF HIGH TENSION VOLTAGE TO THE CURRENT CONSUMPTION—THE MEASUREMENT TAKEN AT TREATER INSTALLED FOR BALBACH SMELTING AND REFINING COMPANY, NEWARK, N. J.

that at which corona started. The bend in this particular curve is somewhat more gradual than is usually found. This is due to a special arrangement of the electrodes whereby the corona starting voltage varies in different parts of the treater.

Fig. 26 shows the results obtained from tests made with various electrode spacings in fume-laden gases at different temperatures. Curve A shows the potential (measured by transformer ratio and the low-tension voltage) which, when rectified, caused a spark-over to occur between a number of parallel wires and a plate placed at varying distances from them.

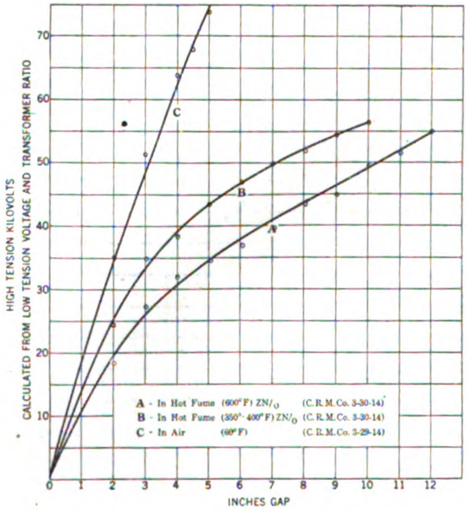


Fig. 26—Curves Showing Sparking Potentials (of Rectified Voltages) between Wires and a Parallel Plate, for Various Gap Spacings

The wires and plates were placed in a flue through which passed zinc oxide fumes at a temperature of 600 deg. fahr. Curve *B* shows similar data obtained with the gas temperature reduced to between 350 deg. and 400 deg. fahr. Curve *C* shows similar data obtained from the same electrode system with air in the flue. The relative positions of curves *A* and *B* are what would be expected. Data are being obtained in order to plot a series of curves between corona starting voltage (ratio method) and electrode spacings. This work has not been completed.

Fig. 27 gives in a specific case the distribution of the electrical losses in transformation, rectification and transmission of the electrical power taken from the supply lines and delivered to the treater. Those of transformation (from 220 volts low-tension) are the greatest. The additional load losses of the transformer are readily calculated. The added load losses of the rectifier are not definitely known but experience indicates that they are small in proportion to the other losses. The added load losses of the transmission line are negligible. These latter losses consist almost entirely of corona loss and insulator leakage both of which depend upon the voltage and not upon the current. From such data it is possible to estimate very closely the capacity of apparatus required to deliver to the treater any given power at a certain voltage.

As for the actual treaters or chambers in which electrodes are installed, several types and sizes have been standardized. These are for widely varying gas conditions. Valuable experience has been had on friction loss of gases passing through treaters, and through inlets and outlets, and on getting uniform gas distribution. The latter is more difficult to control when the velocity of the gas is low than when it is high. Treater construction costs have been greatly decreased.

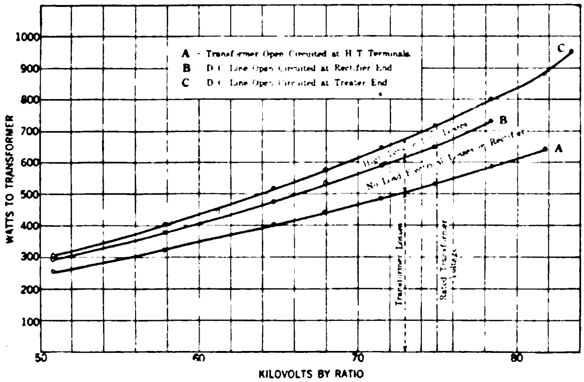


FIG. 27—POWER LOSS DATA

Transformer 7½ kv-a. 75,000-v. 60 ~. Rectifier type—2 arm—8 shoe—steel shaft. Line insulators 2 per line trans. to rect., 11 in d-c. line.

Valuable experience has been had in the field of measuring and sampling large volumes of moving gases, and methods suitable for our work have been evolved which have been proved of practical reliability by results on large scale installations. Several complex flue systems and stacks have been explored and data obtained in such a manner that reliable predictions were possible, as to the effect of the installation of electrical precipitation equipment. In many cases this is a very pertinent question, especially when natural draft is depended upon to move the gases.

TABLE II

EXPERIMENTAL DATA ON 2-TREATER SECTIONS OF TWENTY 14-IN. DIAM. PIPES EACH. SINGLE WIRE ELECTRODE

Time	Tap*	Volts low-tension	Kilo volts high-tension by ratio	Amps low-tension	Watts corrected	Volt-amps.	Power factor	Fan speed.	Difference in static Fan inlet & outlet in oz. per sq. in.
P.M.									
4:30				Run	Started.				
5:00	5	182	57.0	15	2100	2730	0.76	330	1½
5:30	4	170	64.0	25	3500	4250	0.82	323	1½
6:00	4	165	62.0	20	2550	3300	0.77	331	1½†
6:30	4	175	65.7	16	2400	2800	0.85	...	....
7:00	4	172	64.7	17	2500	2924	0.85	320	1
8:40	Both sections cleaned pipes and wires.								
8:45	5	185	58.0	13	2000	2400	0.83	325	1½
9:15	5	194	60.5	10	1500	1940	0.77	320	1
9:40	Pipes rapped section No. 2 shut down for 1 min.								
9:45	5	195	61.0	10	1350	1950	.69	301	1
Readings continued about as above at half hour intervals and pipes cleaned by hammering every hour until 4:00 a. m.									
A.M.									
4:00	5	195	61.0	10	1350	1950	0.69	285	⅞
4:25		Pipes	rapped.						
4:30	5	200	62.5	8	1150	1600	0.72	292	⅞‡
5:00	5	200	62.5	8	1250	1600	0.78	268	⅞
5:35	5	200	62.5	12	1800	2400	0.75	270	⅝
6:00	5	205	64.0	8	1200	1640	0.73	277	⅝
6:30	5	200	62.5	6	1000	1200	0.83	270	⅞
7:00	5	197	61.5	6	1050	1180	0.89	276	⅞
7:30	5	200	62.5	9	1150	1800	0.64	273	⅞
8:20	5	202	63.0	8	1000	1620	0.62	278	⅞
8:30		Run dis	continued						

* Transformer Ratio Tap 4—200 to 75,000 volts.
5—200 to 62,500 "

† Pipes rapped
‡ Pipes rapped at 5:20

The log sheet shown in Table II gives a typical set of readings taken during a run on a two-section treater. Each section consists of twenty 12-in. diameter pipes, 12 ft. long. The log sheet shows a considerable variation of the power consumption

TABLE III

Typical Field Data Sheet

For Sampling Tests Using Electric Precipitator

Research Corporation

July 22-23, 1914

Gage zero	Stack reading 1	V. H. in. H_2O stack 1	Sampler reading 2	V. H. in. H_2O sampler 2	Temp. of stack 1-2	Temp. of treater	Stack vel. ft./sec. 1	Treater 6-in. pipe vel. ft./sec. 2	Stack vol. cu. ft. min. 1	Treater vol. cu. ft. min. 2	Std. vol. stack. 1	Std. vol. treater 2	Per cent handled $\frac{2}{1}$	Time out.	Time.
															Start.
.045	.330	.142	.330	.142	780	380	38.6	38.6	53,200	46.3			0.870	3:30p. m.	3:00 p.m.
045	360	157	350	152	780	450	40.6	39.9	56,000	479			856		4:00
040	430	195	410	185	815	450	46.0	44.7	63,500	536			844		4:30
	400	190	410	185	760	465	44.2	43.6	61,000	523			857		5:00
	300	130	310	135	760	500	36.6	37.3	50,500	448			886		5:30
	310	135	300	130	805	465	38.0	37.3	52,400	448			856		6:00
	280	120	290	125	670	380	33.8	34.5	46,600	414			888		6:30
	200	080	190	075	760	350	28.7	27.8	39,600	334			843		7:00
	200	080	220	090	800	385	28.7	30.4	39,600	365			922		7:30
040	190	075	180	070	780	270	28.1	27.2	38,800	326			842		8:00
040															8:30
045	200	077	420	187	800	320	28.8	44.6	39,700	535			1.350		9:00
050	220	085	230	090	770	270	29.7	30.6	41,300	367			.887		9:30
050	220	085	230	090	750	260	29.4	30.3	40,600	364			.897		10:00
.055			10-11	P.M.	6" line plugged with water drain plugged—no gage reading.										10:30
.050	170	060	290	120	490	180	21.9	31.0	30,200	372			1.225		11:30
.050	170	060	240	095	470	170	21.7	27.3	30,000	328			1.095		12:00 m.n.
.055	420	182	410	177	700	220	42.3	41.7	57,000	500			876		12:30 a.m.
050	460	205	500	225	690	440	44.5	46.5	61,400	570			927		1:00
	440	195	430	190	860	370	46.7	46.0	64,500	552			858		1:30
	420	185	430	190	840	400	45.3	46.0	62,500	552			883		2:00
	390	170	410	180	850	380	43.3	44.6	59,700	535			894		2:30
	350	150	350	150	840	350	40.5	40.5	55,900	486			869		3:00
	240	095	240	095	860	270	32.6	32.6	45,000	391			869		3:30
	280	115	260	105	900	330	36.3	34.7	50,100	435			869		4:00
	410	180	450	200	850	320	44.6	47.1	61,500	535			869		4:30
	450	200	420	185	830	340	46.7	44.8	64,500	538			836		5:00
	480	215	390	170	860	340	49.0	43.5	67,600	522			772		5:30
	470	210	460	250	830	360	47.8	47.3	66,000	527			796		6:00
	420	185	400	175	820	340	44.7	43.4	61,600	521			842		6:30
	480	215	480	215	770	360	47.2	47.2	65,100	506			776		7:00
	420	185	420	185	720	320	42.9	42.9	59,200	514			867		7:30
.050	410	180	410	180	710	320	42.2	42.2	58,200	506			867		8:00
.045	360	157	355	150	685	300	39.1	38.1	54,000	457			846		8:30
.050	400	175	400	175	780	280	44.0	44.0	60,700	528			868		9:00
050	420	185	400	175	700	340	42.6	41.4	58,800	497			845		9:30
															10:00
.040	440	200	425	192	860	420	47.3	46.3	65,300	556			847	10:10-10:50	11:00
045	425	190	420	187	915	520	47.0	46.7	64,900	570			873		11:30
040	460	210	450	205	910	505	49.3	48.8	68,000	586			862		12:00 m.
													32830		

Note: Readings taken and samples drawn 60 ft. above base of stack. Stack 160 ft. in height.

and of power factor. This was one of the first test runs made in application of the electrical processes to a new problem. Causes for each unsteady or unfavorable condition are sought and the effect of each on the percentage of precipitation is noted and steps are taken toward their elimination. Finally with the proper conditions secured, the operation becomes steady and automatic. Electrical data and gas measurements are taken simultaneously.

A typical field data sheet is given in Table III. It was used in connection with flue loss determinations, and is a copy of actual test data obtained in a 24-hour test. (See Fig. 28 for arrangement). From left to right the columns shown give the following information:

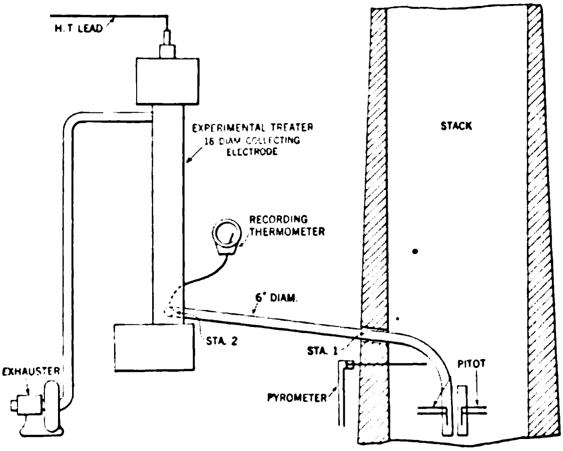


FIG. 28

Column 1. Gage zero—on the differential gage used; a zero reading was always taken.

Column 2. Stack reading—a differential gage reading, indicating the gas velocities in the stack. The gage is connected to a pitot tube in a 6-inch diam. "companion" pipe shown in Fig. 28.

" 3. V.H. in. H_2O Stack—is the gas velocity head in inches H_2O in the stack and is one-half the difference between columns 1 and 2. (Gage factor = 0.5)

" 4. Sampler Reading—is the reading indicated on the differential gage, connected to the pitot tube in the 6 in. dia. sampler pipe. (See Fig. 28).

" 5. V.H. in. H_2O sampler—is the gas velocity heads in inches H_2O in the 6-inch dia. sampler pipe. (Gage factor = 0.5).

Column 6. Temperature of stack gases in degrees fahrenheit.
" 7. " " Gases in treater in degrees fahrenheit.
" 8. Stack Vel. ft. per sec.—velocity of gases in stack.

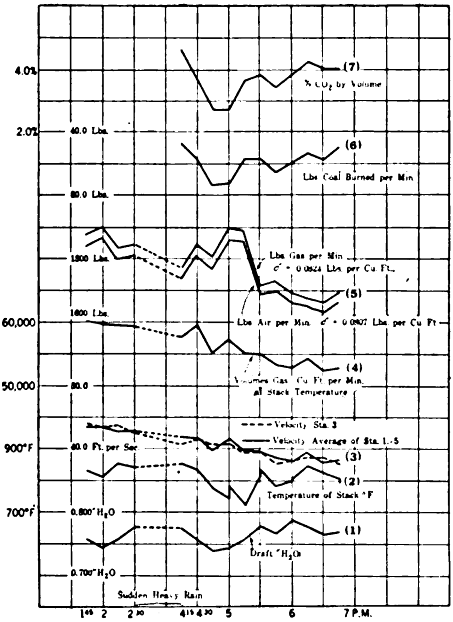


FIG. 29

Weather generally fair—Barometer 29.47 in. Hg.
Elevation of station 440 + 65 = 505 ft. A. S. L.
Barometer correction for velocity;
V from chart × 1.008 = V actual.
Correction for carbon dioxide;
V from chart × 0.990 = V actual (4 per cent CO_2)

Average Results.

Draft : 0.72 in. H_2O
Stack temperature: 808 °F.
Air temperature : 75 °F.
Gas velocity : 40.5 ft. per sec.
Gas velocity (3) : 40.6 ft. per sec.
Gas velocity : 2430 ft. per min.
Gas velocity : 27.2 mi. per hr.
Gas volume : 55,900 cu. ft. per min.

Gas weight : 1745 lb. per min. (air)
weight : 1780 lb. per min. (gas)
Standard volume : 21,600 cu. ft. per min.
CO_2% by volume : 3.67 per cent.
Lb. carbon: 26.6 burned per min
Lb. coal : 30.6 burned per min

Scale

Horizontal:
1 division = 1 hour
Vertical :
0.1 division = 0.02 in. H_2O draft. (1)
= 20°F, stack temperature. (2)
= 1.0 ft. per sec. (3)
= 1000 cu. ft. per min. (4)
= 20.0 lb. per min. gas (5)
= 0.2 per cent CO_2 (7)
= 2 lb. coal (6)

Column 9. Treater 6-inch Pipe Vel. ft. per sec.—velocity of gases in 6-in. diam. sampler pipe to treater.
" 10. Stack Vol. cu. ft. per min.—volume of stack gases per minute.
" 11. Treater Vol. cu. ft. per min.—volume of treater gases per minute.

Column 12. Std. Vol. Stack—volume of stack gases at 32 deg. fahr., 29.92 in. H_g.

" 13. Std. Treater Vol.—Volume of treater gases at 32 deg. fahr., 29.92 in. H_g.

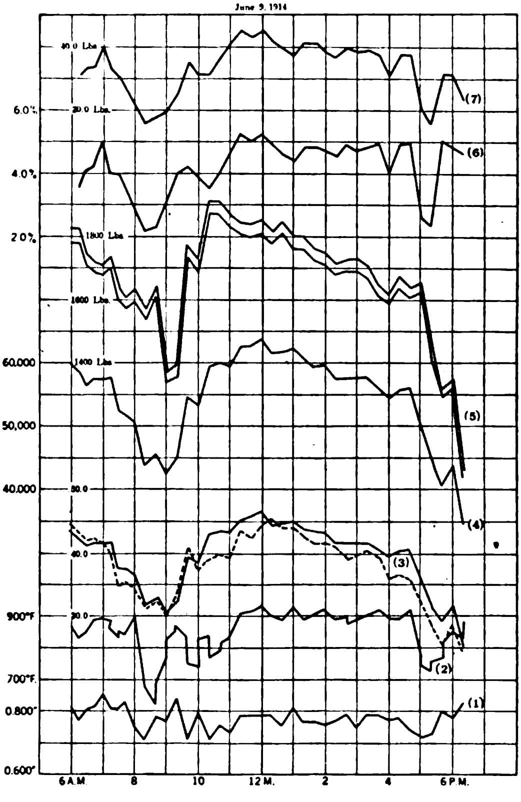


FIG. 30

Scale

Abscissa: 1 division = 2 hours

Ordinate:

(1) 0.1 division = 0.02 in. H_2O draft
(2) = 20°F. stack temp.
(3) = 1.0 ft. per sec. gas velocity
(4) = 1000 cu. ft. per min. gas volume
(5) = 20 lb. per min. gas weight
(6) = 0.2 per cent CO_2 by vol.
(7) = 20 lb. per min. coal burned.

Column 14. Per cent handled—ratio of gases handled in precipitator to total gases in stack.

" 15. Time Out—record of "shut downs" or troubles incidental to the test.

" 16. Time—schedule of readings taken during test.

In connection with the above data, sets of daily measurements were made of the quantities and conditions of the gases in the stack. The detail of these figures is given in the form

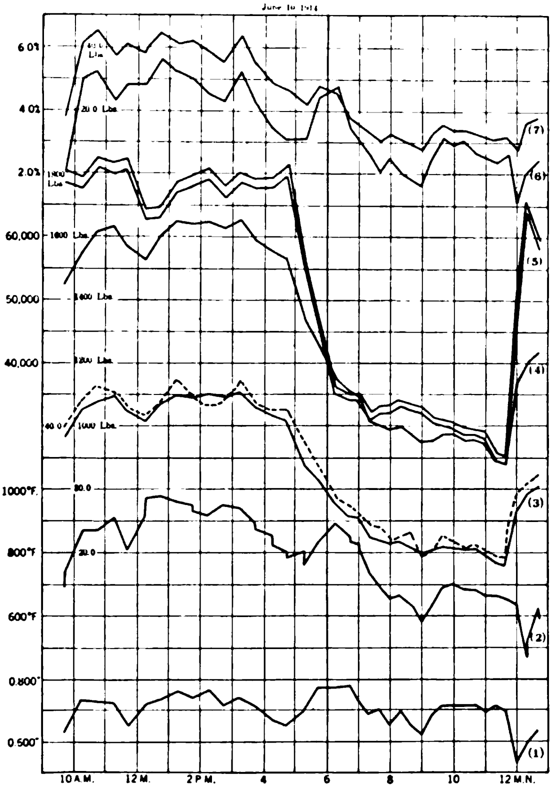


FIG. 31

Scale

Abscissa: 1 division = 2 hours

Ordinate:

(1) 0.1 division = 0.02 in. H_2O draft

(2) = 20°F. stack temp.

(3) = 1.0 ft. per sec. gas velocity

(4) = 1000 cu. ft. per min. gas volume

(5) = 20 lb. per min. gas weight

(6) = 0.2 per cent CO_2 by vol.

(7) = 20 lb. per min coal burned.

of "curve sheets" as Figs. 29, 30, 31 and 32. These results are summarized in Table IV.

Temperature records kept during the above mentioned test are given as Figs. 33 and 34.

In Fig. 35 a sketch of the electric precipitator used for the demonstration in connection with this paper is shown. This sketch includes the method of showing corona effects and the method of producing fume and dust for precipitation, in connection with the experiments prepared for this demonstration.

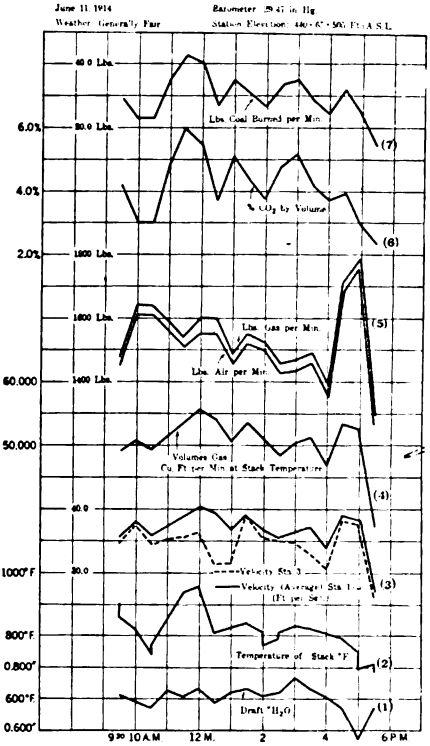


FIG. 32

Scale

Abscissa: 1 division = 2 hours.

Ordinate:

(1) 0.1 division = 0.02 in. H_2O draft.
(2) = 20 °F. (stack)
(3) = 1.0 ft. per sec.
(4) = 1000 cu. ft. per min.
(5) = 20 lb. per min. (gas)
(6) = 0.2 per cent CO_2
(7) = 2 lb. coal per min.

Results

0.700 in. H_2O	average draft
870 °F.	average stack temp.
84 °F.	average air temp.
36.7	average gas velocity
Sta. No. 3 center	average gas velocity 34.4
2200 ft. per min.	average gas velocity.
25.0 mi. per hr.	average gas velocity.
50,700	average gas volume
1520	average gas wt. (air)
1550	average gas wt. (gas)
18,800	average std. volume
4.17	average % CO_2 by volume
26.2	average lb. carbon
30.1	average lb. coal

Several additional installations of these processes have been made under the direction of Mr. Walter A. Schmidt, of Los Angeles, California, at various locations in the Pacific Coast States, Canada, and Germany. The one which treats the largest volume of gases is at the plant of the Riverside Portland Cement Company. The installation at the Smelter near Trail, B. C. treats about 100,000 cu. ft. of gases per minute coming from lead blast furnaces. A treater has been installed for handling the gases from one 1000-barrel cement kiln at Buffington, Indiana, and a continuous thirty day test showed an average of approximately 95 per cent of the dust removed from between 60,000 and 75,000 cu. ft. of gas per minute, the temperature occasionally reaching 750 deg. cent.

TABLE IV

ELEVATION OF STATION 505 FT. A. S. L. BAROMETER 29.47 IN Hg. TOP OF STACK —505 FT. A. S. L. STACK HEIGHT—160 FT.

	1	2	3	4	5	6	7
Date	Day June 8-14	Day June 9-14	Day June 9-14	Average 2 & 3	Day June 10-14	Night June 10-14	Day June 11-14
Period of Measurement.	1:45p.m. to2:30 " 4:15 " to 6:45 "	6 a.m. to 12 m.	12:20 to 6:20 pm.		9:45A.m 5:45pm.	6:45pm 12:40 a. m.	.9:30am 5:30pm
Velocity of gas feet per sec.	40.5	42.1	39.3	40.7	41.7	21.7	36.7
Velocity of gas. Feet/minute.	2430	2520	2360	2440	2520	1320	2220
Miles/hour.	27.2	28.6	26.6	27.6	28.6	15.0	25.2
Flue temperature °F.	810	830	880	855	870	690	870
Volume of gas cu. ft/min. @ flue temperature.	55,900	58,100	54,300	56,200	58,000	30,200	51,000
Volume of gas. cu. ft/min at 29.92" Hg. 32° F.	21,600	22,150	19,900	21,050	21,450	12,900	18,900
Weight of gas passing lbs min.	Air .1745 Gas 1780	1790 1825	1610 1640	1700 1735	1730 1765	1040 1060	1525 1555
% CO_2 by vol.	3.67	4.00	4.47	4.24	4.36	2.12	4.17
Calculated lb. carbon burned per minute.	26.6	29.6	29.7	29.65	31.3	9.12	26.2
Calculated lb. coal burned per minute.	30.6	34.1	34.2	34.15	36.0	10.5	30.4
Stack draft inches H_2O.	0.720	0.781	0.775	0.778	0.712	0.692	0.700
Sets of fires.	1-8	1-8	1-8	1-8	1-8	1-4	1-7
No. of fires.	88	88	88	88	88	48	78
Air temp. °F.	75	61	67	64	80	77	84

In conclusion it is to be stated that the past three years have

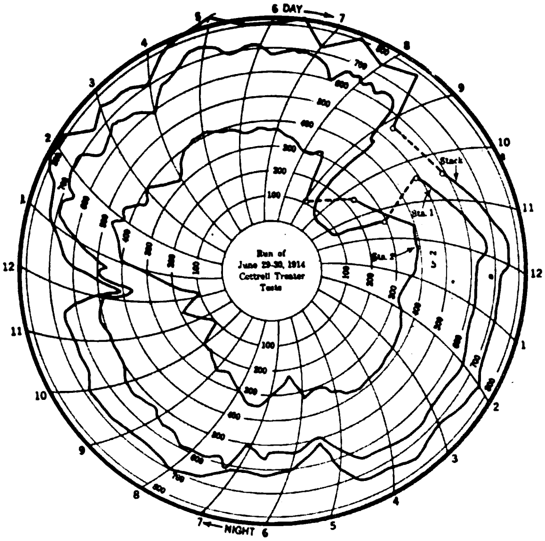


FIG. 33—TEMPERATURE RECORDS IN CONNECTION WITH ELECTRIC PRECIPITATOR TESTS

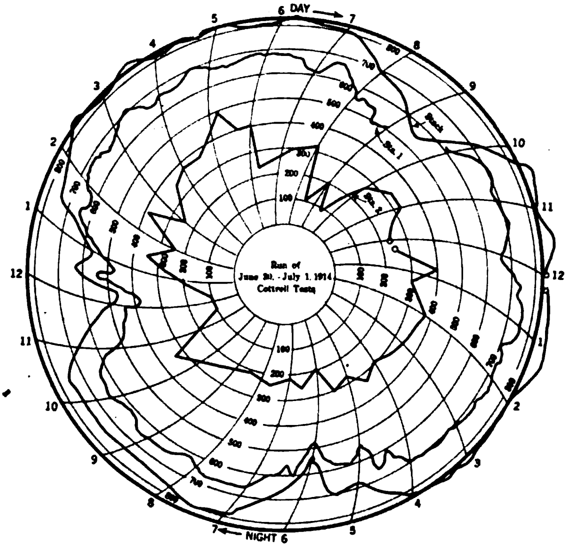


FIG. 34—TEMPERATURE RECORDS IN CONNECTION WITH ELECTRIC PRECIPITATOR TESTS

seen the electrical processes (Cottrell patents) in constantly growing use and demand, several commercial installations having produced excellent results, and that the future is full of promise. The corporation has definitely established itself commercially in the short time intervening since its organization. The total capital paid into the treasury was $10,100. From the receipts so far obtained for technical services and for patent rights, all the corporation's stockholders have been fully repaid, and there is on hand at present nearly $150,000 in good and negotiable securities as a net surplus, with only ordinary current accounts owing. Further income as royalties from installations now in operation, under way, or contracted for, will materially increase the above amount, so that a fund for further scientific research has already been created, and this directly from the industries benefited by the processes administered by the corporation.

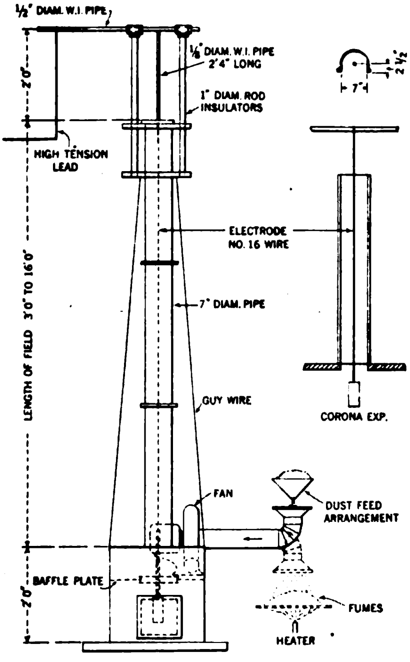


FIG. 35—DEMONSTRATION TREATER

Surely the record of the results obtained, both those technical and commercial, and the indications observable from direct personal contact with the ever-growing and widening field, and the actual inquiries received, warrant and justify the statement that the electrical processes and the movement represented in the Research Corporation have been definitely established and that the future holds vastly more of promise than the past.

Messrs. H. D. Egbert, P. E. Landolt, A. F. Meston, C. I. Weir, J. C. Hale, H. A. Burns, H. M. Pier, assistant engineers in the employ of the corporation have rendered very valuable service in connection with the various problems which have been encountered and have materially aided in overcoming the many difficulties. They have been very loyal and devoted to the cause, working in the main under very unfavorable conditions and receiving smaller compensation during most of the three years the corporation has been operating than they could have obtained elsewhere, and they are to be complimented and thanked for their zealous and efficient service. The technical men in the various plants have likewise taken a keen interest in the work and have rendered valuable services and have been of great assistance in enabling the presentation of a report of such progress and thanks are due them.

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CONTINUOUS WAVES IN LONG DISTANCE RADIO TELEGRAPHY

BY L. F. FULLER

Abstract of Paper

Ability to predetermine the probable normal daylight-sending radius of high-powered radio telegraphic stations is of prime importance in their design.

The theoretical transmission equations for both continuous and damped waves are discussed and the empirical formulas for the latter are given.

Experiments with continuous waves over a period of six months between San Francisco and Honolulu, a distance of 2100 nautical miles (3880 km.), are described, and an empirical formula for the calculation of probable sending radius with such waves is proposed. This is checked by experiments between Tuckerton, N. J., and Honolulu, 4330 nautical miles (8000 km.)

Curves giving the energy received at Honolulu from San Francisco under both day and night conditions are shown, and the effects of changes in wave length upon transmission efficiency are discussed. Evidence strengthening theories of the reflection, refraction and interference of Hertzian waves in long distance transmissions and experimental data showing interference bands not over 18 miles in width is given. The great value of easy and rapid changes in wave length, especially at night, is apparent from the curves.

Final conclusions drawn from a comparison of the empirical transmission formulas for continuous and for damped waves are that the transmission efficiency of continuous waves is somewhat higher than that of damped waves on wave lengths of approximately 3000 m. or above, and that this advantage increases with the wave length.

Theoretical Features

THE comparative transmission efficiency of continuous and damped waves has been the subject of much discussion. Most experimental attempts to study the question have been over moderate distances and no difference has been observed until recently. Austin[1]* states that experiments of the United States Navy Department from the Arlington station, using a Poulsen arc for the generation of continuous waves and a 500-cycle spark transmitter for the production of damped waves have shown that at distances of the order of 2000 nautical miles (3700 km.), or above, continuous waves are on an average superior.

Manuscript of this paper was received March 10, 1915.

*Reference numbers refer to the bibliography at end of paper.

A theoretical analysis of the transmission of electro-magnetic waves, either continuous or damped, over a perfectly conducting plane was given by Somerfeld[2] in 1909. Further treatment of the subject has been given by Poincaire[3], Nicholson[4], March[5], von Rybczynski[6] and Zenneck[7]. Certain experimental data over short distances have also been given by Duddell[8] Taylor[8] and Tissot[9].

In 1912, Eccles[10] gave a theoretical discussion of the propagation of electromagnetic waves in long distance transmission around the curvature of the earth. His conclusions are strengthened by the United States Navy Department's tests of 1910 and 1913, recorded by Austin[1, 11] and by the Federal Telegraph Co. Poulsen arc, San Francisco-Honolulu tests of 1914, to be described herein.

The results of the Sommerfeld theoretical treatment of the transmission problem may be stated as follows for continuous waves.

$$E = 120\,\pi\,\frac{h_1\,I_s}{\lambda\,d}\sqrt{\frac{\theta}{\sin\theta}}\;e^{-\frac{0.0019\,d}{\lambda\;1/3}} \tag{1}$$

where E = effective electric amplitude in volts per km. of the electric field at a distance (d) from the sending antenna.

h_1 = effective height of sending antenna in km.

I_s = current in amperes at base of sending antenna.

λ = wave length in km.

d = distance in km.

θ = angle at center of earth subtended by distance d.

It is assumed that the earth is perfectly conducting and that d is several wave lengths.

If the waves are damped, then on account of the wave train form of the oscillations.

$$E = 120\,\pi\,\frac{h_1\,I_s}{\lambda\,d}\,\frac{\sqrt{\dfrac{\theta}{\sin\theta}}}{\sqrt{1+\dfrac{\delta_1}{\delta_2}}}\;e^{-\frac{0.0019\,d}{\lambda\;1/3}} \tag{2}$$

where δ_1 and δ_2 are the decrements of the transmitter and receiver respectively.

Solving equation (1) for I_R the current in amperes at the base of the receiving antenna of effective height h_2 km. and of resistance R ohms, we obtain for continuous waves:

$$I_R = \frac{Eh_2}{R} = 120\,\pi\,\frac{h_1\,h_2\,I_s}{\lambda\,d\,R}\sqrt{\frac{\theta}{\sin\theta}}\cdot e^{-\frac{0.0019\,d}{\lambda^{1/3}}} \tag{3}$$

and from equation (**2**) for damped waves:

$$I_R = \frac{Eh_2}{R} = 120\,\pi\,\frac{h_1\,h_2\,I_s}{\lambda\,d\,R}\,\frac{\sqrt{\dfrac{\theta}{\sin\theta}}}{\sqrt{1+\dfrac{\delta_1}{\delta_2}}}\cdot e^{-\frac{0.0019\,d}{\lambda^{1/3}}} \tag{4}$$

This may be divided into four terms:

(1) $$120\,\pi\,\frac{h_1\,h_2\,I_s}{\lambda\,d\,R}$$

which is the Hertzian expression for the effective value of the current flowing through a resistance at a point in the equatorial plane of an equivalent oscillator of length h at a distance d.

(2) $$\sqrt{\frac{\theta}{\sin\theta}}$$

takes account of the curvature of the earth.

(3) $$\sqrt{1+\frac{\delta_1}{\delta_2}}$$

takes account of the damping at both transmitter and receiver and is therefore unity for continuous waves.

(4) $$e^{-\frac{0.0019\,d}{\lambda^{1/3}}}$$

corrects for the divergence of energy into the upper strata of the atmosphere due to the waves not following perfectly the curvature of the earth and might be termed a "divergence factor."

All these theoretical equations are for a perfectly conducting earth surface. Von Rybczynski states that a slight decrease in conductivity will result in a slight increase in received energy, apparently due to a reduction in the divergence factor. A considerable reduction in earth surface conductivity, however, will result in severe loss, and an absorption factor[13] must be introduced. This is the case in most overland transmissions.

It is obvious therefore, that theoretical transmission formulas must vary with the type of earth surface over which transmission is effected, and that empirical formulas derived from experimental data will likewise vary, the only certain uniformity possible in earth surface conductivity being over sea water. Atmospheric conditions affecting electromagnetic waves are so variable during the hours of darkness that it is only under normal day conditions that uniformity can exist. Hence, the only relatively uniform basis upon which theoretical and empirical formulas may be compared is for transmission over sea water under normal day conditions.

In 1911 Austin[11] gave the results of quantitative experiments up to 1000 nautical miles (1850 km.) from a spark transmitter at Brant Rock, Mass., and again[14] in 1914 with a spark transmitter from the United States naval radio telegraphic station at Arlington, Va. up to 2000 nautical miles (3700 km.). These experiments with the damped wave may, according to Austin (loc. cit.) be expressed by the following semi-empirical formula:

$$I_R = 120\pi \frac{h_1\, h_2\, I_s}{\lambda\, d\, R} \sqrt{\frac{\theta}{\sin\theta}} \cdot e^{-\frac{0.0015\, d}{\sqrt{\lambda}}} \tag{5}$$

The term $\sqrt{\frac{\theta}{\sin\theta}}$ may be considered as unity for distances of 2000 nautical miles (3800 km.).

The main point of difference between this and the theoretical Sommerfeld formula for the damped wave is in the last term, the divergence factor, $e^{-\frac{0.0015\, d}{\sqrt{\lambda}}}$ instead of $e^{-\frac{0.0019\, d}{\lambda^{1/3}}}$.

This makes long distance radio telegraphy much easier than theory would indicate and is probably due to a return of energy from the upper atmosphere by reflection or refraction, or both. Presumable therefore, a convergence factor might be added to the theoretical formula. From much data available, especially that to be presented herein on the San Francisco-Honolulu sustained-wave experiments of 1914, it is probable that such convergence is considerably greater with continuous than with damped waves. No experimental data are available from any source on the effects of changes in decrement on transmission efficiency and divergence factor over long distances.

The foregoing covers briefly the theoretical equations of long distance radio transmission for both continuous and damped waves and the empirical formula of Austin for damped waves. This formula (**5**) proves quite satisfactory for the ordinary calculations of practical work, and would indicate that a change should be made in the theoretical equations to account for the considerable increase in received energy noted seemingly due to convergence; *i. e.* a return to the earth's surface, near the receiver, of energy radiated into the upper atmosphere after leaving the transmitting station.

GENERAL DESCRIPTION

The following description of the San Francisco-Honolulu sustained wave tests of 1914 may be divided into two parts.

1. That dealing with the effects of wave length upon the strength of received signals. This has an accuracy which is satisfactory for comparative results, and probably averages within 10 per cent.

2. That part covering the derivation of a proposed empirical formula for sustained wave transmission. This has an accuracy below that which could have been obtained had the two stations involved not been handling commercial work, which necessitated the taking of experimental data at irregular intervals, and caused frequent interruptions. It is probably accurate within 20 per cent.

Thus all deductions based upon the relative value of received energy readings may be considered as being considerably more reliable than those based upon actual received energy values.

It is believed, however, that all data are of sufficient accuracy for practical purposes and that the transmission formula for continuous waves may be satisfactorily used in commercial design.

DESCRIPTION OF PLANTS

The data presented herein were taken during the period of six months, extending from January to June, 1914, inclusive. The range of wave lengths was from 3000 to 11,800 meters, and the distance of transmission 2100 nautical miles (3880 km.).

The stations were the San Francisco and Honolulu plants of the Federal Telegraph Co. Both were equipped with 100 kw. Poulsen-Federal arc transmitters rated on continuous d-c. input, although 40-50 kw. is the usual power employed.

Each had three guyed wooden towers, two 440 ft., and one 608 ft. in height, giving triangular flat top antennas of 0.010 mf. capacity.

At San Francisco the 440-ft. towers were 600 ft. between centers. The 608-ft. tower was 900 ft. from one, 1095 ft. from the other 440-ft. tower.

At Honolulu all towers were on 600-ft. centers, forming an equilateral triangle and there was in addition, the arc of approximately 135 degrees of an umbrella antenna, strung from the back side of the 608-ft. tower over shallow tide water. This accounts for the capacity of this antenna with the close tower spacing being the same as that at San Francisco.

The center of capacity at Honolulu was very close to 394 ft. (120 m.), while at San Francisco, due to greater sags, it was approximately 380 ft. (116 m.).

METHODS OF TAKING DATA

Antenna Currents were measured by hot-wire ammeters calibrated from a 100-ampere Hartmann-Braun unshunted hot band instrument used as a standard.

Wave Lengths were measured by a standard wave meter[15] employing a tikker and phones to indicate resonance.

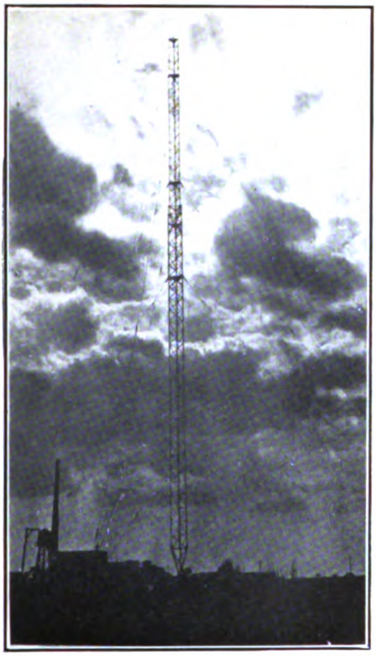
Centers of Capacity were determined by mapping the triangular net work of the antennas giving the height above the earth for various areas, and assuming a low capacity for the down leads.

Received Watts were determined by the shunted telephone method. The general procedure was identical with that used in the U. S. Navy Department tests of 1910 and 1913 described by Austin[11, 1] and was briefly as follows:

If the receiving telephones be shunted by a variable resistance, the incoming signal has an audibility of one when the shunting resistance is so adjusted that the dots and dashes can just be differentiated. The following relation then exists:

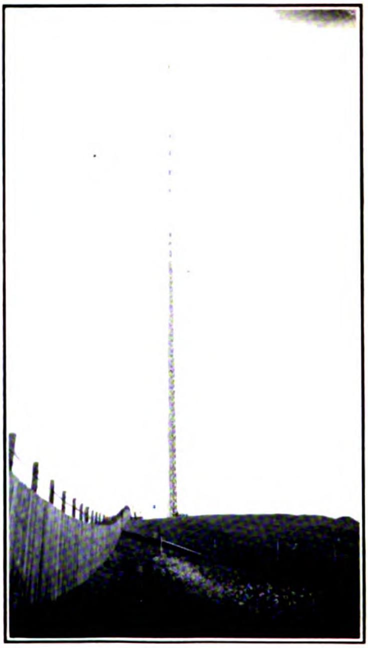
$$A_f = \frac{R + S}{S} \tag{6}$$

where A_f = audibility factor or number of times audibility.
R = impedance of telephones in ohms.
and S = impedance of resistance shunting telephones in ohms.



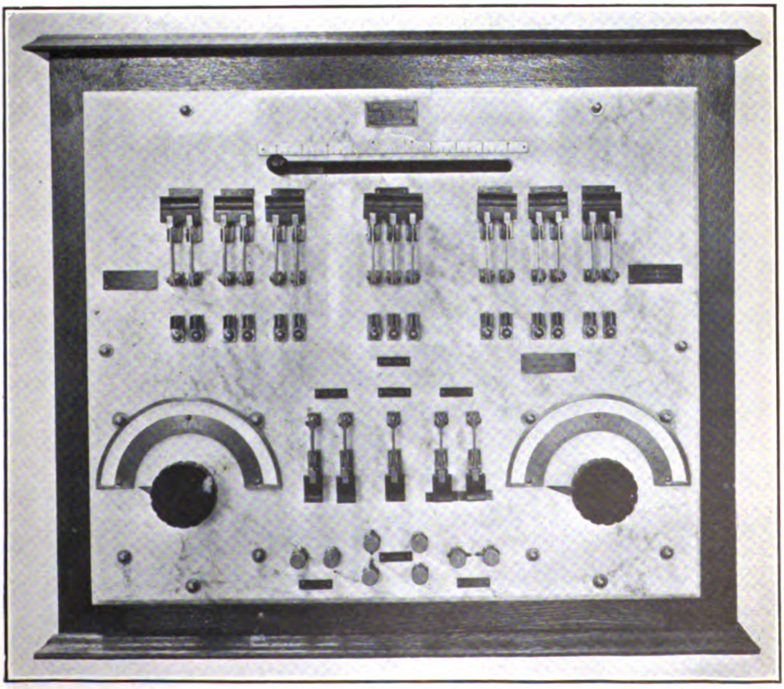
[FULLER]

EIGHT HUNDRED AND TWENTY FIVE-FT. STEEL TOWER AT TUCKERTON, N.J.



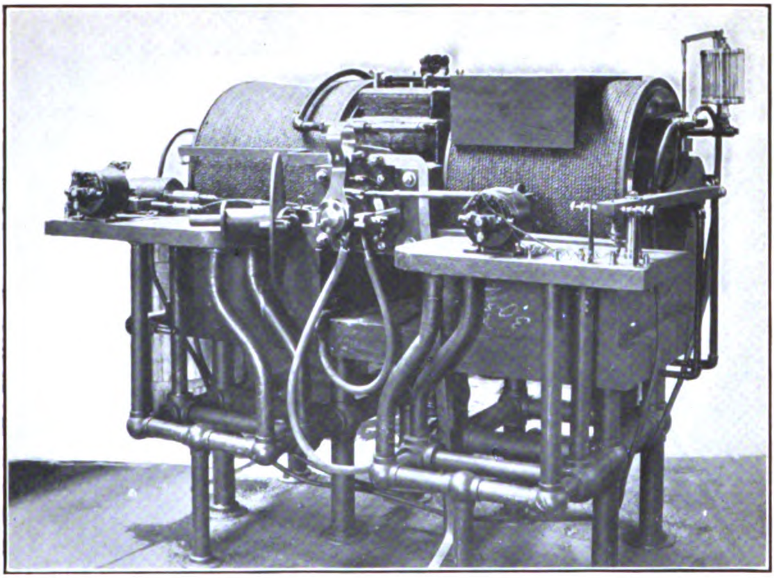
[FULLER]

SIX HUNDRED AND EIGHT-FT. TOWER AT SAN FRANCISCO



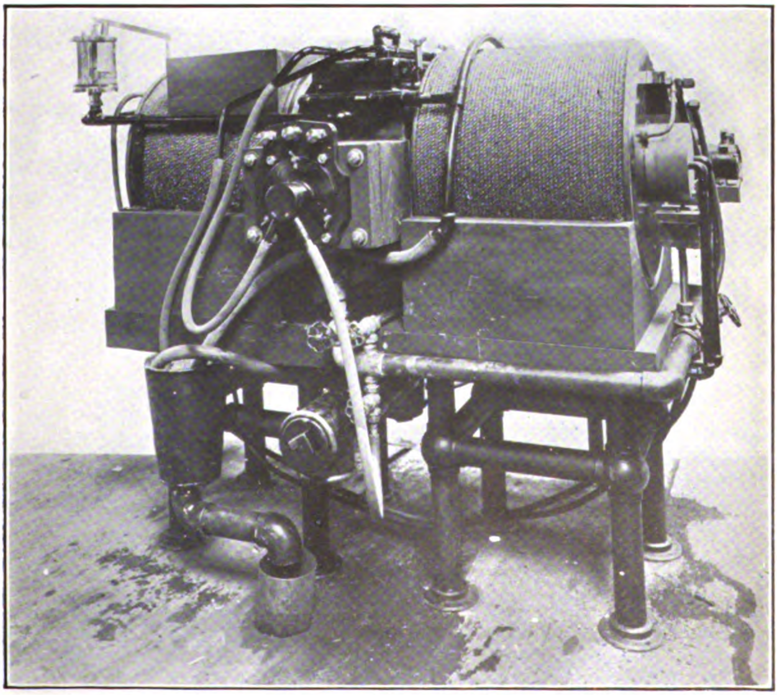
[FULLER]

TYPE OF RECEIVING APPARATUS USED AT HONOLULU AND SAN FRANCISCO DURING TESTS



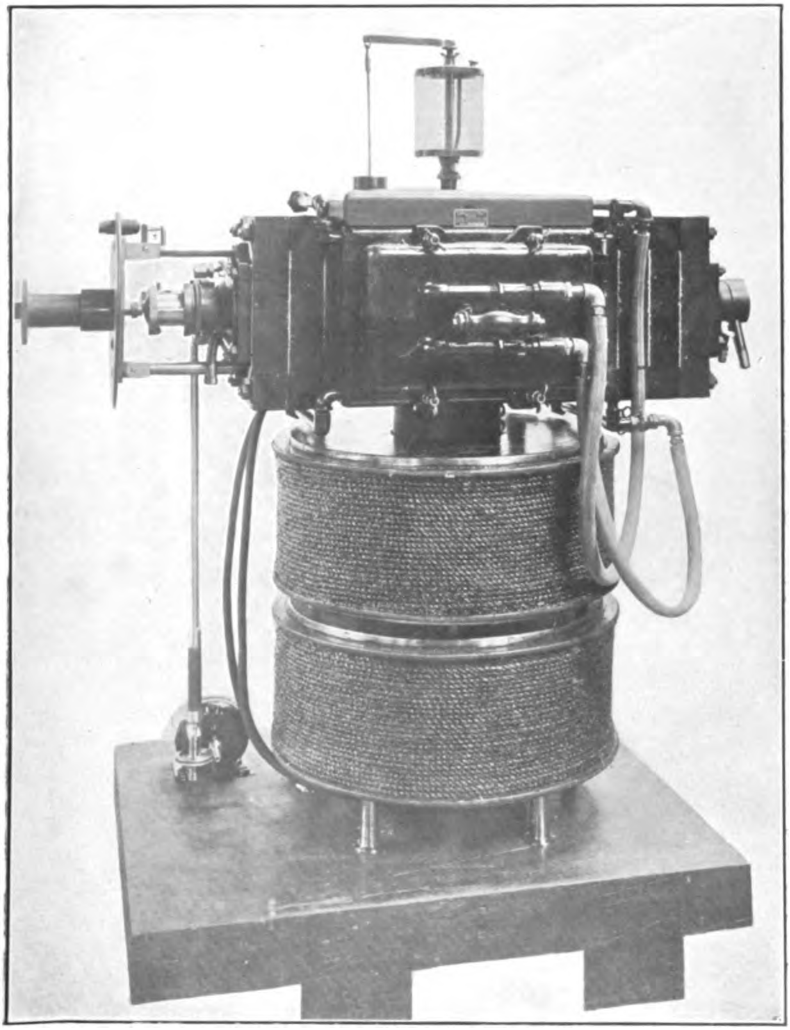
[FULLER]

FRONT VIEW 100-KW. POULSEN-FEDERAL ARC TRANSMITTER USED AT SAN FRANCISCO AND HONOLULU DURING TESTS



[FULLER]

BACK VIEW 100-KW. POULSEN-FEDERAL ARC TRANSMITTER



[FULLER]

THIRTY-KW. POULSEN-FEDERAL ARC TRANSMITTER

For the purpose of determining the received watts for a given value of resistance shunting the phones, or for a given audibility factor, another Poulsen-Federal arc station near by was used as a transmitter, and a thermo-couple and galvanometer were inserted in the antenna of the receiving station. These had previously been calibrated on direct current and indicated the received antenna current.

Measurements of the resistance of the antenna circuit, with the secondary of the receiver adjusted to resonance, were made throughout a range of wave lengths extending from 3000 to 10,000 meters, and the received watts for a known audibility factor were calculated by RI^2. These values of received energy were reduced to received watts for unit audibility. Using a rotary tikker and sensitive telephone receivers these results gave the relation

$$P = 3.2 \times 10^{-10} A_f \tag{7}$$

where P = received energy in watts and
A_f = audibility factor as defined above.

General Notes

Reference to the tabulated data shows the general average of signal strength obtained with the antenna current at the transmitter reduced to 35 amperes.

It was kept below 50 amperes in order that a minimum error might be introduced in correcting received current for a constant transmitting antenna current for all wave lengths. Preliminary investigation of this point showed that for transmitting antenna currents somewhat above 50 amperes the received current did not vary directly as the transmitting current[16] but fell off somewhat.

In order to eliminate as far as possible factors tending to cause questionable results, the antenna current in all tests was kept at such a value as to make it possible to correct received current with certainty to the values which would have been obtained had it been convenient to hold the tranmsitting antenna current constant for all wave lengths.

All data are for transmission with daylight over the entire path except on a certain few night tests. With the exception of ten miles of bare hills approximately 1200 ft. in height at the San Francisco end, the path of transmission lies entirely over sea.

DISCUSSION OF CURVES

Figs. 1, 2, 3, and 4 show received energy as a straight line function of the wave length. It is possible that during these tests the waves were subjected to refraction only and that the amount of energy received by reflection from the upper atmosphere was small, probably indicating stable day conditions.[17]

The data in Fig. 5 show a constant gain in received energy up to 7000 meters with a second peak at 10,000 meters.

Fig. 6 is somewhat similar; again showing a maximum at 7000 meters, a minimum between 8000 and 9000 and a rise again at 10,000 meters.

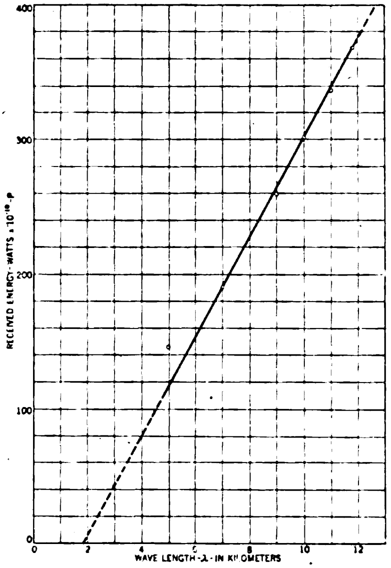


FIG. 1—HONOLULU TO SAN FRANCISCO, JAN. 25, 1914,—SAN FRANCISCO TIME 1:05 P.M.-2:55 P.M.—I_s = 35 AMPERES.

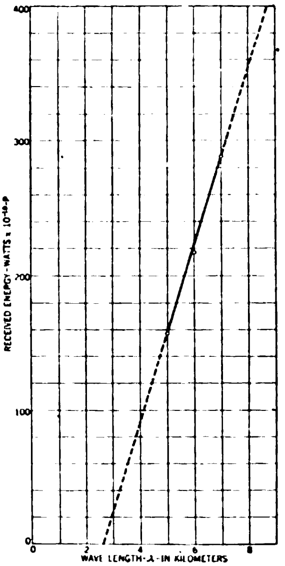


FIG 2—SAN FRANCISCO TO HONOLULU, JAN. 25, 1914—SAN FRANCISCO TIME 9 A.M. - 12 M. —I_s = 35 AMPERES.

Fig. 7 is also of this same general type. All three indicate a combination of day and night conditions with possibly partial interference on certain wave lengths, and addition on others, due to a combination of reflection and refraction phenomena.

Fig. 8 is a typical night curve showing a marked reduction in signal strength on certain wave lengths, probably due to reflection phenomenon. When compared with Fig. 13, however, it will

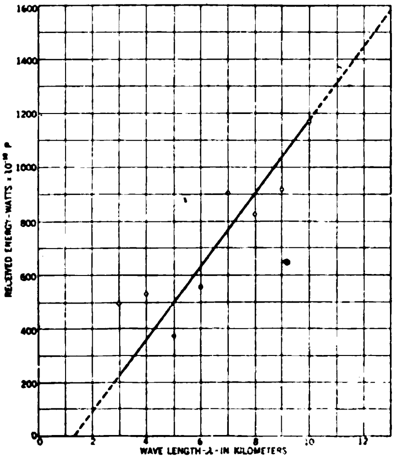


FIG. 3—HONOLULU TO SAN FRANCISCO, MARCH 1, 1914—SAN FRANCISCO TIME 10 A.M.-12 M.—I_s = 35 AMPERES.

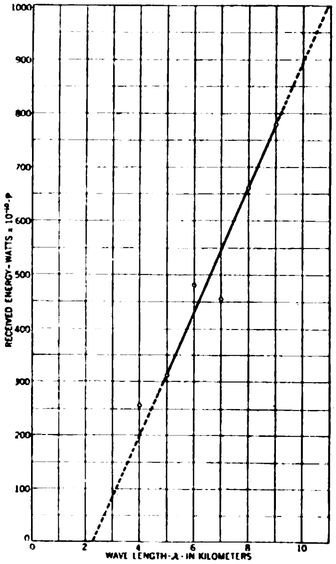


FIG. 4—HONOLULU TO SAN FRANCISCO, MARCH 8, 1914—SAN FRANCISCO TIME 11:44 A.M.-12:03 P.M.—I_s = 35 AMPERES.

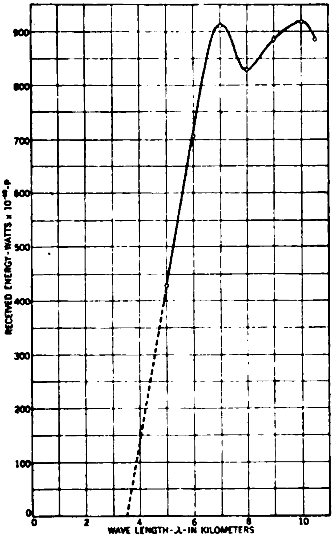


FIG. 5—HONOLULU TO SAN FRANCISCO, MARCH 8, 1914—SAN FRANCISCO TIME 3:08 P.M.-3:54 P.M.—I_s = 35 AMPERES.

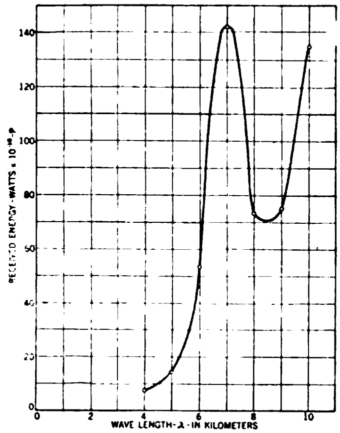


FIG. 6—HONOLULU TO SAN FRANCISCO, MARCH 15, 1914—SAN FRANCISCO TIME 10:30 A.M.-12 M.—I_s = 35 AMPERES.

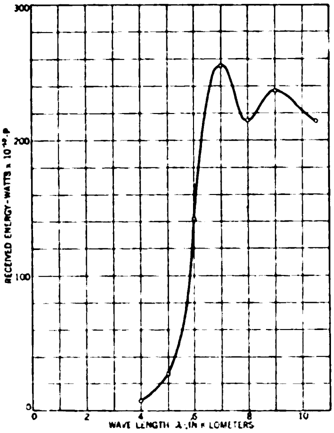


FIG. 7—HONOLULU TO SAN FRANCISCO, MARCH 15, 1914—SAN FRANCISCO TIME 3 P.M. 4 P.M.—I_s = 35 AMPERES

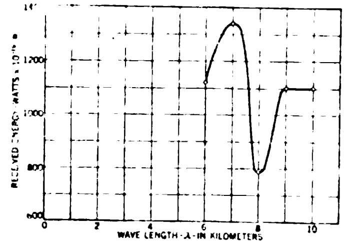


FIG. 8—HONOLULU TO SAN FRANCISCO, APRIL 1, 1914—SAN FRANCISCO TIME 3 A.M.-4 A.M.—I_s = 35 AMPERES.

Typical night curve showing a marked reduction in signal strength on certain waves.

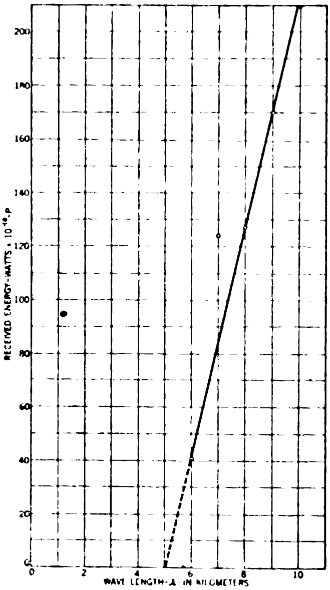


FIG. 9—HONOLULU TO SAN FRANCISCO, MAY 3. 1914—SAN FRANCISCO TIME 10 A.M.-12 M.—I_s = 35 AMPERES.

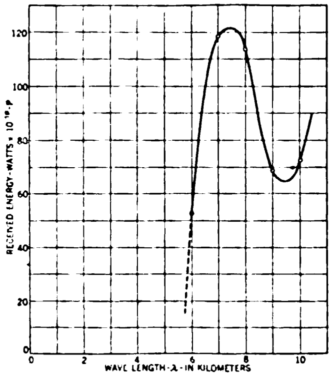


FIG. 10—HONOLULU TO SAN FRANCISCO, MAY 17, 1914—SAN FRANCISCO TIME 11:30 A.M.-12 M. —I_s = 35 AMPERES.

be noted that the efficiency of transmission on the night of April 1 must have been considerably lower than on the night of June 13th, since no reduction in received energy following the radiation resistance curve is noted in the former case. This shows that the reduced losses in transmission on the long waves more than counter-balanced the reduction in radiation resistance. The great difference in observed audibilities on these two nights also indicates this fact.

Fig. 9 again shows a constant daylight condition, the received energy being a straight line function of the wave length, probably indicating consistent refraction and no reflection.

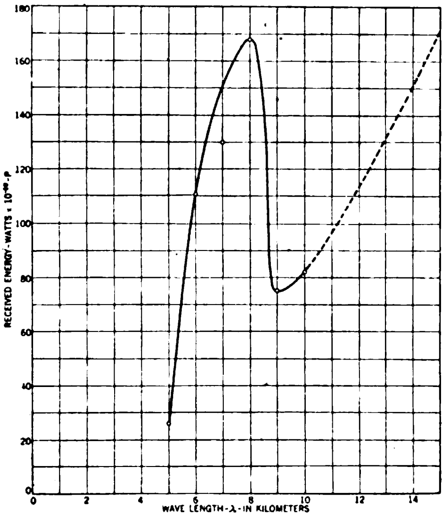


FIG. 11—HONOLULU TO SAN FRANCISCO, MAY 24, 1914—SAN FRANCISCO TIME 10:25 A.M.-11:25 A.M.—I_s = 35 AMPERES.

Fig. 10 is interesting in again showing a maximum near 7000 meters; but the 8000- and 9000-meter waves show a decrease. Judging from the last two points on this curve, and from the behavior of curves in Figs. 11, 12, 14 and 15, it is probable that this curve, if continued, would show an increase in received energy.

Figs. 11 and 12 show a maximum at 8000 and 7000 meters respectively, a minimum at 9000 meters, and a decided rise at 10,000 meters. It is thought quite probable that at 14,000 and 16,000 meters, the double of 7000 and 8000 meters, other maximums might be noted. These are shown by dotted extensions.

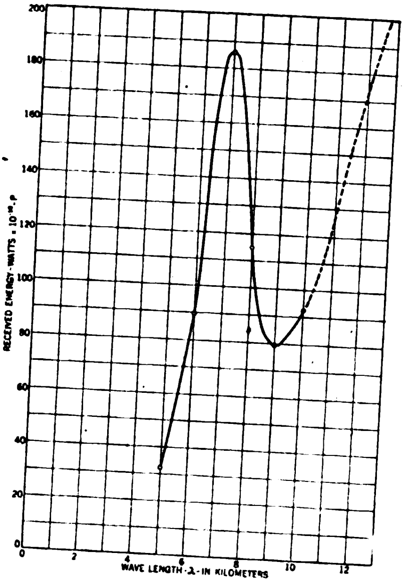


FIG. 12—HONOLULU TO SAN FRANCISCO, MAY 24, 1914—SAN FRANCISCO TIME 11:25 A.M.-12:05 P.M.—I_s = 35 AMPERES.

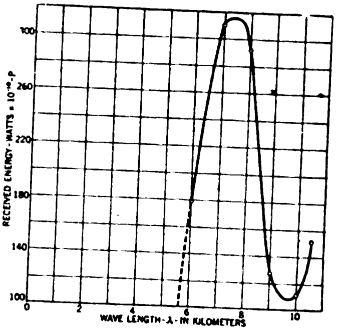


FIG 14—HONOLULU TO SAN FRANCISCO, JUNE 22, 1914—SAN FRANCISCO TIME 10:30 A.M.-11:15 A.M.—I_s = 35 AMPERES.

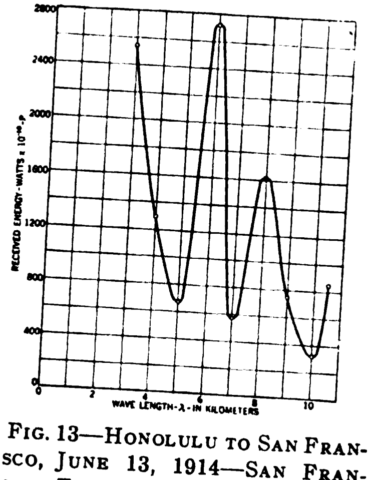


FIG. 13—HONOLULU TO SAN FRANCISCO, JUNE 13, 1914—SAN FRANCISCO TIME 2:45 A.M.-3:30 A.M.—I_s = 35 AMPERES.

Typical night curve showing marked reduction in signal strength on certain waves.

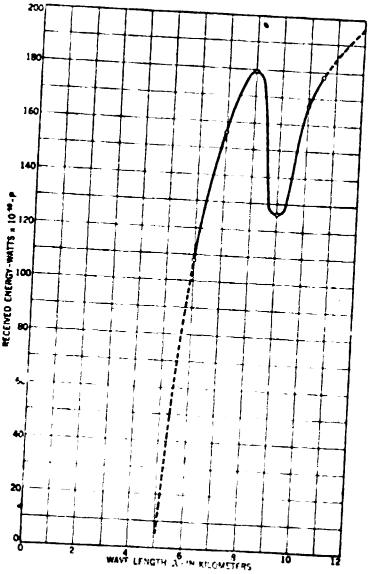


FIG. 15—HONOLULU TO SAN FRANCISCO, JUNE 28, 1914—SAN FRANCISCO TIME 10:45 A.M.-10:30 A.M.—I_s = 35 AMPERES.

Fig. 13 is another typical night curve, similar to Fig. 8, showing a marked reduction in signal strength on certain waves. It is interesting to note that the average of these points gives a curve which follows the radiation resistance curve of the transmitting station, showing a falling off of the received energy in proportion to the reduction in the radiation resistance at the transmitter. For reasons given in the discussion of Fig. 8, the efficiency of transmission must have been very high and reflection phenomenon marked at the time Fig. 13 was taken.

Figs. 14 and 15 are typical examples of the unstable daylight class, probably indicating refraction, and in addition, reflection and a resulting interference upon certain wave lengths.

From a half hour to two hours time elapsed during the taking of each set of observations. During this period the conditions of absorption for various wave lengths could have changed materially. However, many sets of observations are the results of two sets of readings, giving identical curves although separated by one half to three quarters of an hour. It may be assumed with reasonable accuracy therefore, that as a whole, the observations for any given date recorded herein present conditions existing simultaneously on all the wave lengths. This is undoubtedly true of the data showing stable day conditions and this is the only data from which deductions and calculations have been made.

It is probably not true, however, of the pure night curves, Figs. 8 and 13. At night, conditions of apparent absorption may vary by several hundred per cent. within a few minutes. The fact that the mean values of Fig. 13 follow the radiation resistance curve, however, would tend to show that conditions were fairly uniform throughout the period during which its observations were made.

AN EMPIRICAL TRANSMISSION FORMULA FOR CONTINUOUS WAVES

The observed data are presented in the accompanying tables and from these the curves of the fifteen plates are drawn.

Calculations have been made from data taken from the curves *as drawn*. Only curves or parts of curves which show stable daylight conditions have been used. These are:

Fig 1. All waves
" 2. " "
" 3. " "
" 4. " "

OBSERVED DATA
Corrected to I_S = 35 Amperes

Fig. No.	Wave Length Meters λ	Received Energy Watts $\times 10^{-10}$ P
1.	5000	145.
	7000	190
	9000	259.
	10000	301
	11000	336.
	11800	368.
2.	5000	157.
	6000	217.
	7000	288.
3.	3000	496.
	4000	531.
	5000	371.
	6000	557.
	7000	905.
	8000	829.
	9000	919.
	10000	1170.
4.	4000	255.0
	5000	312.0
	6000	480.0
	7000	454.0
	8000	660.0
	9000	778.0
5.	5000	429.0
	6000	707.0
	7000	911.0
	8000	830.0
	9000	886.0
	10000	919.0
	10500	886.0
6.	4000	7.8
	5000	14.6
	6000	53.6
	7000	142.0
	8000	73.3
	9000	75.2
	10000	135.0
7.	4000	7.8
	5000	27.2
	6000	142.0
	7000	255.0
	8000	215.0
	9000	237.0
	10500	214.0
8.	6000	1120.0
N	7000	1340.0
i	8000	788.0
g	9000	1100.0
h	10000	1100.0
t		
9.	6000	40.7
	7000	124.0
	8000	127.0
	9000	170.0
	10000	210.0
10.	6000	52.5
	7000	118.5
	8000	113.8
	9000	68.4
	10000	72.2
11.	5000	26.0
	6000	110.8
	7000	130.0
	8000	168.0
	9000	75.0
	10000	82.0
12.	5000	32.0
	6000	89.6
	7000	186.0
	8000	114.5
	9000	79.4
	10000	92.5
13.	3000	2540.0
	4000	1295.0
N	5000	668.0
i	6000	2720.0
g	7000	576.0
h	8000	1610.0
t	9000	743.0
	10000	320.0
	10500	842.0
14.	6000	179.0
	7000	310.0
	8000	292.0
	9000	127.0
	10000	111.0
	10500	151.0
15.	6000	107.5
	7000	156.0
	8000	179.0
	9000	126.0
	10000	167.0
	10500	178.0

Fig. 5. 5000-7000 meters
" 6. 6000-7000 meters
" 7. 6000-7000 meters
" 9. All waves

If in formula (**3**) the last term, the divergence factor $e^{-\frac{0.0019\,d}{\lambda^{\frac{1}{2}}}}$ be written e^{-Ad} and the whole formula be solved for A we obtain

$$A = \frac{1}{d} \log e\, 120\,\pi \frac{h_1\, h_2\, I_s}{\lambda\, d\, R\, I_R} \sqrt{\frac{\theta}{\sin\theta}} \qquad (\mathbf{8})$$

Twenty five separate calculations of A by the above formula have been made from data taken from the curves on wave lengths ranging from 3000 to 11,800 meters. From these it may be said that for continuous waves.

$$A = \frac{\beta}{\lambda\sqrt{2}} \qquad (\mathbf{9})$$

within the limits of error of these observations.

In the above equation the average of twenty five values of β is 45×10^{-4}.

The exponent of λ shown in equation (**9**) holds consistently through all data while β varies from day to day. The value given above was the average observed during these tests. The maximum noted occurred on March 15th on 6000 meters when β reached a value of 77×10^{-4}. The minimum noted was on March 8th on a 9000-meter wave when β dropped to 20×10^{-4}.

Substituting equation (**9**) and the above average value of β in formula 3, we obtain the following daylight transmission formula for continuous waves over sea water:

$$I_R = 377 \frac{h_1\, h_2\, I_s}{\lambda\, d\, R} \sqrt{\frac{\theta}{\sin\theta}} \cdot e^{-\frac{0.0045\,d}{\lambda\sqrt{2}}} \qquad (\mathbf{10})$$

where all factors are expressed as in formula (**3**).

No attempt has been made to give an average value of β for night work since it may vary by many hundred per cent within a few minutes and a few hundred meters change in wave length may make a variation of the same order of magnitude. Figs. 8 and 13 illustrate these points. It is also obviously useless to attempt the approximation of β for day work during periods when partial night conditions exist. All such conditions usually tend to reduce the apparent absorption upon certain waves and increase it upon others. Hence in using formula (**10**) for the calculation of *average* sending radius and received signal strength it may be considered safe to use the average value of β given above provided the transmitting station has several waves at its disposal. If its available wave lengths are limited, however, it is liable, at times during which unstable day conditions exist, to be forced to transmit on a wave having poor transmission efficiency. With such stations it is obviously safer to use a value of β more nearly the maximum noted above for the calculation of *average* sending radius. The value to be used is naturally controlled to a great extent by the importance of the station, the quality of service required, and the geographical location.

During November and December, 1914, tests were carried on by the United States Navy Department from the Goldschmidt high-powered radio telegraphic station at Tuckerton, N. J. to the Honolulu plant of the Federal Telegraph Company. Signals were transmitted in daylight the entire distance of approximately 4330 nautical miles (8000 km.) using a rotary tikker detector in receiving at Honolulu.

The antenna at Tuckerton consists of 36 wires attached to the top of a steel tower 825 ft., (250 m.) in height. The outer ends of these wires are attached to poles 40 ft. (12 m.) high arranged in a circle of 1500 ft. (450 m.) radius with the steel tower at the center. The wave lengths used by Tuckerton were 7400 and 10,000 meters. The shorter wave was never heard in Honolulu in daylight, but the longer was received consistently during the tests with daylight over the entire path of transmission. On the 7400-meter wave, both a Goldschmidt alternator and a Poulsen-Federal arc were used, but on the 10,000-meter wave only the arc was available.

Certain further checks on formula (**10**) are possible from these tests. These are as follows:

At San Francisco, approximately 2000 nautical miles from Tuckerton, the ratio of received currents for the 10,000- and 7400-meter waves was

$$\frac{I_{R\ 10000\ m}}{I_{R\ 7400\ m}} = 1.56 \text{ observed and } 1.67 \text{ calculated}$$

This is primarily a check upon the $\sqrt{2}$ exponent of wave length and the constant β of 45×10^{-4} in the divergence factor.

At Honolulu a received current of 5.5×10^{-6} amperes on 10,000 meters was observed. The calculated value from formula (**10**) is 6.12×10^{-6} amperes.

On the 7400-meter wave from Tuckerton, formula (**10**) gives a value of received current below audibility and this is roughly checked by the fact that this wave was never heard until noon Honolulu time, which was 5:30 p.m. at Tuckerton. This late in the day, normal conditions no longer exist and night conditions are beginning. The calculations are made from the following data:

I_s = 122 amperes on 10,000 meters and 100 amperes on 7400 meters
h_1 = 300 ft. = 91.5×10^{-3} km.
h_2 = 197 ft. = 60×10^{-3} km.
λ = 10 km. and 7.4 km.
d = 4330 nautical miles = 8000 km.
At Honolulu { R_{10000} = 150 ohms. High resistance due to close coupling, mediocre ground, and series receiving circuit.
R_{7400} = 135 ohms.
θ = 72.5 degrees.
A_f = 14.25 times audibility at Honolulu on 10,000-meter wave and zero on 7400-meter wave.
P_R = 3.2 x 10 watts for unit audibility.

No consistent difference was noted at San Francisco or Honolulu in the energy received from the alternator as compared with the arc when both were transmitting upon the same wave length and delivering the same antenna current.

The general conclusions to be drawn from the San Francisco-Honolulu and Tuckerton-Honolulu tests of 1914 are as follows:

(1) Under normal day conditions the comparative transmission efficiency of continuous waves is somewhat higher than that of damped waves on wave lengths above 3000 meters. The last term, the divergence factor of formula (**10**), compared with that of formula (**5**) shows this.

(2) The transmission efficiency of continuous waves generated either by a Goldschmidt reflection alternator or a Poulsen-Federal arc would seem to be the same.

(3) In transmissions over distances in the order of 4000 nautical miles, intervening land appears to be the equivalent of sea

water, at least during the winter months. This may be due to the greater part of the received energy traversing the upper strata of the atmosphere.

(4) In the 15 curves shown in the figures, much evidence is found adding weight to the theories of refraction, reflection and interference upon certain wave lengths. These are further borne out by observations made at the Beach station of the Federal Telegraph Company, nine miles from the high-power plant described herein. Very frequently a wave length used by Honolulu, which is excellent at one, is useless at the other, and as atmospheric conditions change, conditions are reversed. This plainly shows interference bands not over 18 miles in width. Such phenomena are most apparent at night when reflection is pronounced.

(5) Ability to change wave lengths rapidly is of the greatest value in long distance radio telegraphy. Fig. 13 shows this to good advantage.

Formula (**10**) was derived from a distance of approximately 2000 nautical miles (3700 km.) and has been checked by the data presented herein for a distance of approximately 4330 nautical miles (8000 km.) It is believed that it is of sufficient accuracy for ordinary practical purposes and it is hoped it may be satisfactorily used in commercial design. It must always be borne in mind, however, that variations of 100 per cent or more may occur from day to day under seemingly identical conditions at both transmitter and receiver, and also that the formula was derived from data obtained by waves traveling over the waters of the North Pacific Ocean, which, as a rule, permits of greater transmission efficiency than is found in some other parts of the world.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the help received from his assistants, Messrs. R. R. Beal, E. B. Murphy and F. C. Ryan at San Francisco, and from Messrs. S. B. Maddams and H. L. Rodman at Honolulu.

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11. L. W. Austin, *Bul. Bu. Stds.*, Vol. 7, p. 315; 1911. Also *Jahrb. d drahtl. Teleg.*, Vol. 5, p. 75; 1912.

12. The effective height of an antenna may be taken as one half the length of the equivalent Hertzian oscillator and is equal to the height above the earth of the centre of capacity of the antenna if the earth is perfectly conducting and large conducting masses are not near by to distort the electrostatic field. Often measurements of received energy at short distances upon receiving antennas of definitely known effective heights are necessary for proper determination.

13. J. Zenneck, *Ann. d. Phys.*, Vol. 23, p. 846; 1907. Also Lehrb. d. drahtl. Teleg., p. 297.

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15. G. W. Pierce, Principles of Wireless Telegraphy, p. 216.

16. A power overloading of the antenna and resultant atmospheric ionization in the vicinity of the transmitting antenna may be a factor in this phenomenon.

17. H. Parodi, *La Lumiere Elec.*, April 11-18, 1914. Also H. Barkhausen, *Elec. Zeit.*, April 16, 1914. Also W. H. Eccles and J. A. Fleming (10).

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To be presented at the 308th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 15, 1915.

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INDUSTRIAL CONTROL IN THE FOUNDRY

BY R. H. McLAIN

ABSTRACT OF PAPER

Most of the control devices which are required in a foundry do not differ very materially in their functions from control devices in other industries. However, they have to encounter an unusual degree of dirt. Proper enclosing cases and the latest types of safety protection are advantageous. The crane requires a special kind of control. The difference between alternating-current control and direct-current control is discussed and it is shown that for most cases, where cranes are properly selected and arranged, there is no need of converting alternating current into direct current to accommodate foundry cranes.

CONTROL apparatus in the foundry plays the same vital part as in other industries in regard to safety to operators, safety to apparatus and speed of production. Indeed safety to the operator and apparatus is important and profitable, not only for humanitarian reasons, but also as an aid in causing continuity and speed in production. Most of the controllers in foundries present problems which are no different from those in other industries, except possibly that there is more dirt in a foundry than elsewhere. Grinders, mixers, blowers, lifting magnets, etc. are the same in the foundry as elsewhere and really require no separate treatment. A foundry crane, however, is different from other cranes, due to the requirement for a very uniform low value of creeping speed for certain operations. Some new devices have been recently developed which have a peculiar relation to the foundry, such as electric welding, electric furnaces, etc. It is the object of this paper to deal briefly with those types of control which resemble closely the control in other industries and to deal more fully with the theoretical side of crane control.

Miscellaneous machines, such as blowers, grinders, mixers, dryers, conveyers, etc. require good substantial hand or automatic starters, capable of starting the apparatus a few times a day. The reliability of these controllers and the safety are greatly enhanced by enclosing them and thus protecting work-

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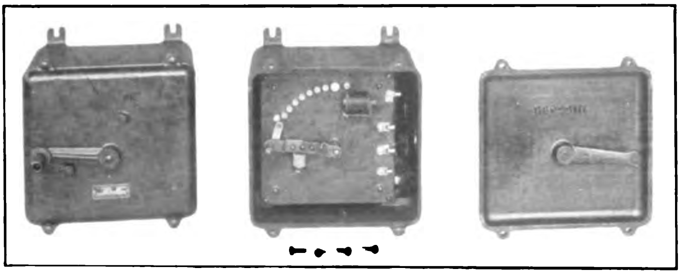
Manuscript of this paper was received March 3, 1915.

men from live parts, and also the controller from dirt. Figs. 1 and 2 show simple hand and automatic starters provided with enclosing covers. Figs. 3, 4 and 5 show a recent development which has been brought about by the great attention which is now being given to safety. These illustrations show a totally enclosed self-starter with line switch, fuses and two contactors for automatic starting. The contactors are controlled by a push button station. The cover is so interlocked with the line switch that it cannot be opened at the bottom unless the line switch is open. The line switch cannot be closed unless the cover is closed. As shown in Fig. 3, the cover can be locked so that an unauthorized person cannot tamper with the fuses or other parts of the controller. As shown in Fig. 4, the cover can be locked in an open position so that the switch must remain open and no power can be applied to the motor. This idea of enclosing all exposed live parts and providing maximum protection to workmen is gaining in popular favor every day, and I believe all controllers which are near workmen, especially those on cranes, where the operator is always close to the controller, should be thoroughly covered.

Lifting magnets are very valuable in many of the larger foundries where large quantities of scrap or pig-iron have to be handled. As is the case with so many other devices, it seems that the control is the key to the situation here. In large magnets it is difficult and dangerous to disrupt the exciting current suddenly because the long induced arc burns up the controller parts, and the high induced voltage will ultimately destroy the insulation of the magnet winding. To overcome these objections, a discharge rheostat is connected to the solenoids before the exciting circuit is interrupted. Of course, the discharge rheostat causes the magnet to be very slow about losing its magnetism, and consequently in releasing its load. Controllers are provided with a spring-return reverse point which gives, through preventive resistance, a partial reverse exciting current, so as to hasten the release of the load. Reverse excitation need not be used except where it is advantageous to gain time by so doing.

The controlling devices used for arc welding equipments and electric furnaces are usually combinations of hand and automatic and are comparatively simple.

Arc Welding. The standard arc-welding generator delivers power at from 60 to 75 volts, and the amount of current used



[McLAIN]

FIG. 1—COMPLETELY ENCLOSED HAND STARTER FOR DIRECT-CURRENT MOTORS

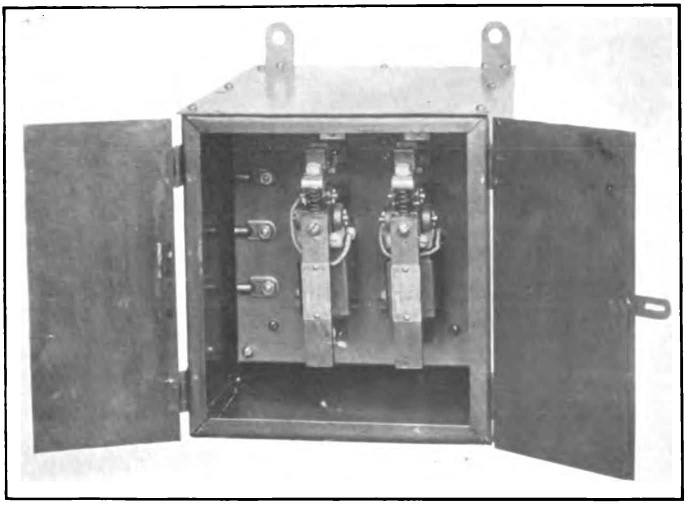


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FIG. 2—THREE-POINT AUTOMATIC STARTER WITH SHEET IRON ENCLOSING CASE FOR DIRECT-CURRENT MOTORS

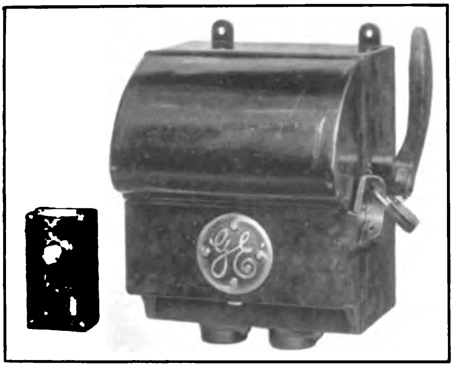

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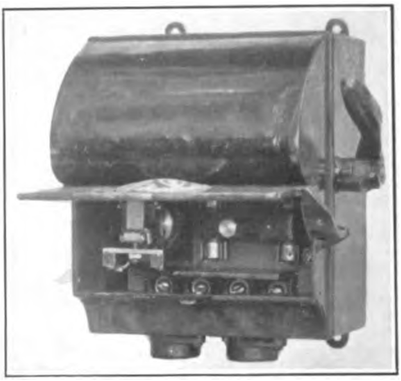
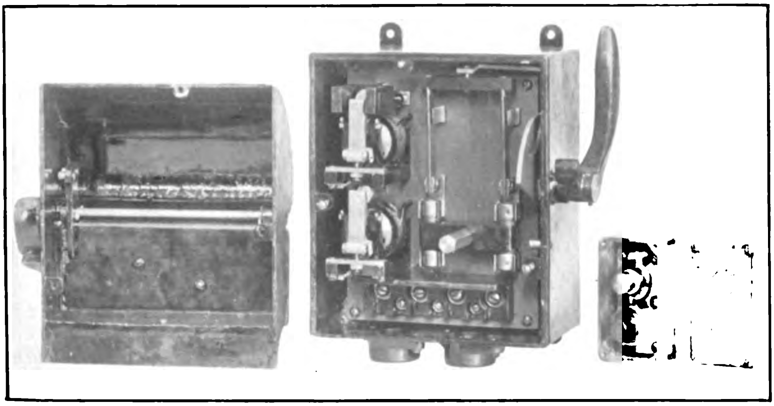
FIG. 3—TWO-POINT CONTACTOR PANEL FOR SMALL DIRECT-CURRENT MOTORS PROVIDING SAFETY PROTECTION TO OPERATOR



[MCLAIN]

FIG. 4—TWO-POINT CONTACTOR PANEL FOR SMALL DIRECT-CURRENT MOTORS PROVIDING SAFETY PROTECTION TO OPERATOR



[MCLAIN]

FIG. 5—TWO-POINT CONTACTOR PANEL FOR SMALL DIRECT-CURRENT MOTORS PROVIDING SAFETY PROTECTION TO OPERATOR

is varied by a rheostat in series with the arc. In small capacities a dial switch is used and in large capacities knife blade switches give better results.

In order to protect the generator against overloads and make it unnecessary for the operator to leave his work to close circuit breakers, an automatic protection is given by a series relay controlling a shunt contactor that normally short circuits a preventive resistance. When too much current is taken, the preventive resistance is connected in series with the arc and the operator is prevented from injuring the generator and disturbing other operators.

Arc Furnaces. The use of arc furnaces in refining steel requires a constant power control which is obtained by a balanced current relay controlling contactors for starting, stopping and reversing the electrode motors. This control has advantages over devices formerly used, especially in comparative freedom from opening the main oil switch. A double-throw switch is connected in the control circuit whereby the control can be operated by hand on starting the furnace, and thrown over to automatic control as soon as the furnace reaches normal operating conditions.

Electric Resistance Furnaces. In electric resistance furnaces, operating at lower temperature, such as are required for various kinds of heat treatments and melting non-ferrous metals and alloys, a constant temperature control is used. This is accomplished by varying the voltage impressed on the furnace by taking advantage of the characteristics of the resistor which in this type of furnace decreases in resistance as the temperature increases, and vice versa.

By manipulating a simple relay the contactors are arranged to connect the resistor to a low voltage when the current has increased to a certain point, and to a high voltage when the current has decreased in a similar way. The operation of this control equipment has been very successful, the chart obtained from a recording pyrometer giving practically a straight line.

CRANE CONTROL

The crane is the most important, as well as the most expensive, electrically-operated machine in a foundry, and consequently, a very careful, scientific study of the requirements should be made before selecting cranes. The distribution of heavy and light cranes over the floor should be made to suit the work. A very good solution of this problem in a large foundry is to have large overhead cranes and small sidewall traveling cranes, which serve as feeders to the large ones and which can pass under them.

Maximum full-load hook speed, for which the motor is geared, is of vital importance. A careful analysis of the amount of work to be done and the delicacy of the operations should be made, and the proper speed determined from this. It is clearly evident that a locomotive, geared to run at 60 miles per hour, would not pull uniformly or slowly enough when drawing a thin pattern from the sand, and furthermore this high speed would be of no advantage in increasing the output of the foundry. The temptation is always to make the speed as great as possible, but there are certain definite limits beyond which it is not advisable to go. Forty feet per minute is a speed which has met with very general favor on five-ton cranes, and even 60 feet per minute is in use in at least one merchant foundry where every conceivable kind of work is done. Fifteen feet per minute is quite common on larger cranes. The only trouble on cranes geared for the higher speeds, is that at times a uniform creeping speed of some low value, around one to five feet per minute, must be obtained for drawing patterns, etc. With direct current it is not so hard to obtain this creeping speed, whereas with alternating current it is very hard unless the crane is geared for a slower speed than the direct-current crane. In either case, a well built crane, a good system of mechanical brakes and such other things, make a decided difference in the accuracy of control. However, with all other conditions equal, alternating current is at a disadvantage.

I know of a case where a crane is designed to take care of only one kind of work, and when this crane was first proposed, 40 feet per minute was, as a matter of course, chosen for the proper maximum hook speed. The crane was to be used for drawing very thin patterns and was to be driven by alternating-current motors. An investigation of the exact cycle of operation of the crane showed that a hook speed of 12 ft. per min. would do just as much work in a day as would 40 ft. per min. With this lower hook speed, alternating current was ideal in operation. Indeed, there are few cases where it is necessary to change the form of power from alternating current to direct current merely to accommodate foundry cranes, provided the crane itself is built properly, fitted with the proper mechanical load brakes and the maximum full-load hook speed is of the correct value.

On a crane running at 60 ft. per min., or less, a controller viewed from the standpoint of the operator, really needs only two points for hoisting and two points for lowering. The first point should give a uniform creeping speed regardless of the load, and would be used for performing delicate operations. The second point on the controller should give maximum speed, and would be used for making quick trips in transferring the material. Of course in ordinary commercial controllers more than two points of control are necessary in order to transfer the motor speed, without undue shock, from the creeping speed to the maximum speed and vice versa; and there is no objection, from an operating standpoint, to having several such points of control. To obtain this desired form of control in a hoisting direction, a simple rheostatic controller can be used, because the torque on the motor depends directly on the amount of hook load, and the speed can be controlled simply by inserting resistance in series with the armature, or into the secondary circuits of a wound-rotor induction motor, thereby cutting down the speed to the desired point. However, for lowering loads, the tendency is for the load to make the motor run away, and it is necessary either to use dynamic braking control or to equip the crane with some form of a "mechanical load brake." This "mechanical load brake" is an automatic friction braking device which not only holds back against the falling hook load, but also requires power from the motor to drive it in a downward direction; consequently, in so far as the motor is concerned, the work and method of control for lowering is very much like the conditions when the hook is being hoisted, except that the torque required from the motor is practically constant regardless of the amount of load on the hook, whereas in hoisting, the torque depends directly upon the hook load.

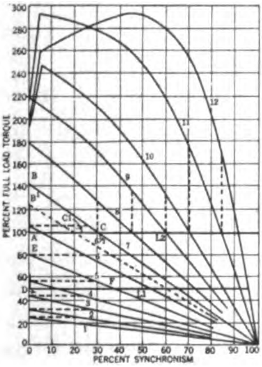


Fig. 6—Speed-Torque Curves of Wound-Rotor Induction Motor when Controlled by 12-Point Rheostatic Controller

Fig. 6 shows the speed-torque curves of a wound-rotor induction motor on the various points of a 12-point rheostatic controller, arranged for foundry service. The object to be attained in laying out such a controller is to provide rheostats of sufficient value and also a sufficient number of controller points, so that as low a value of creeping speed can be obtained as is desirable or necessary for whatever range of torque values the motor will encounter. This particular controller is so arranged that for any value of torque between 18 per cent and 200 per cent, a point can be found on the controller which will give a speed of about 25 per cent or less. By using a larger number of controller points, the value of creeping speed could be kept still lower. In fact, from a strictly theoretical standpoint, by using an infinite number of points, any desired creeping speed of a uniform value could be obtained. However, under practical conditions, there are certain limitations to the benefit which could be thus obtained.

The slip of a motor for a given torque varies on each of these controller points inversely as the square of the line voltage, and this element alone upsets theoretical results. Furthermore when the gearing of a crane is revolving at low speed, the torque required on the motor is not absolutely uniform but varies sometimes with a slight eccentricity of some part, or as the gear teeth mesh in and out. The resistance elements change in value with temperature. Furthermore, there is always considerably more torque required in order to break static friction when starting the load than is later required to hoist it. All of these variable quantities tend to produce a non-uniform creeping speed on this form of motor; consequently for an operator to maintain a uniform—or practically uniform—creeping speed, it is necessary for him to be continually passing the controller from one point to another. Under such conditions, the advantage to be obtained in having a very large number of points disappears, and it becomes more important that a controller be provided whose design is so substantial and positive that the controller itself does not introduce any more variables into the system than already exist. The resistance material should be made ample in quantity so as not to change its ohmic resistance appreciably due to temperature; and the controller handle should be so made that its movement is relatively large in proportion to the amount of change in motor speed which it produces.

With a controller arranged as is shown in Fig. 6, and provided with large travel of handle and substantial type of resistance, it is easily possible to handle, on a well designed crane, any kind of foundry work for maximum hook speeds up to something like 40 to 60 ft. per min. However, a great deal of care would be required from an operator to obtain the desired uniformity of speed control when trying to maintain a speed of around 10 per cent. On account of this, it is not advisable to use such a high maximum hook speed where a large percentage of the time is spent in maintaining such a creeping speed. In a large number of merchant foundries there is, of course, only a rare necessity for having extreme low speeds and at all other times the high maximum speed is of great advantage.

I have made a few calculations which show, in definite figures, how quickly an operator is required to turn his controller from one point to another in order to keep the speed down to a low value.

Assume a load requiring 100 per cent torque from the motor for hoisting, but as is usually the case, assume that 25 per cent extra torque is required to break static friction. It will, therefore, be necessary to turn the controller to point seven, Fig. 6, before the motor will start. The motor will accelerate to 30 per cent of normal speed if the controller is left on this point. The area *A B C* represents the value of torque available for accelerating. If we assume that 100 per cent of the motor torque would be required to accelerate the load, crane and motor parts to full speed in one second, we have the following speed-time curve:

5	per cent	speed	in	0.128	seconds,
10	"	"	"	0.284	"
15	"	"	"	0.484	"
20	"	"	"	0.774	"
25	"	"	"	1.224	"

Since it is an easy matter for a trained operator to act in less than 0.2 seconds, the operator will have ample time to turn back to point 6 before the speed reaches more than 7½ per cent. The hook would then proceed at a uniform speed of 5 per cent on point 6. The above statements, of course, presuppose absolute uniformity of supply voltage and frequency, also uniform torque requirements from the motor.

In order to compare operation with an infinite number of points as against a definite number of points, I have drawn in the dotted line between point 6 and point 7 (6½). This represents the speed-torque curve which gives exactly the correct value of torque to start the load, viz. 125 per cent. On such a point, we would have the following speed-time curve:

5 per cent speed in 0.218 seconds,
10 " " " 0.514 "
15 " " " 1.014 "

It will be seen that on this point, the motor would attain a uniform speed of 20 per cent unless the controller was turned back to a position corresponding to point 6, and it is, therefore, evident that there is no particular advantage in having an infinite number of points unless perhaps it gives the operator a little bit more time in which to act. However, unless such a controller is so constructed that the travel of the handle, corresponding to a change from one torque curve to the other, is large, such an advantage immediately disappears. Since the total travel of the controller handle is necessarily limited to that which is convenient for an operator's hand, the limit to the advantage of adding to the number of controller points is quickly reached.

A third speed-time curve has been calculated for a condition of load that requires 50 per cent of the motor torque. Under this condition with a static friction requiring 62½ per cent to start, point 5 would have to be used and the speed-time curve would be as follows:

5 per cent speed in 0.18 seconds,
10 " " " 0.39 "
15 " " " 0.64 "
20 " " " 0.95 "
25 " " " 1.37 "
30 " " " 1.99 "

It will be seen that the operator will have ample time to turn back to point 4 before a speed exceeding 7½ per cent is reached. In this case he would have to jog along between points 3 and 4 in order to maintain a speed less than 7½ per cent. As stated in the paragraph above, all of these calculations presuppose that several factors remain constant, whereas in fact these factors do not remain constant, and for this reason a great deal of skill and attention is required of an operator in order to maintain a speed as low even as 10 per cent.

When a direct-current, series-wound motor is used, speed-torque curves as shown in Fig. 7 can be obtained by rheostatic control in exactly the same manner as is shown for alternating current in Fig. 6. A typical case would be represented by a controller which would provide curves, point 1, point 2, point 3, point 4 and point 5, and with such a controller the same difficulty in maintaining a creeping speed would be encountered as with alternating current,—that is to say, such a controller would begin to introduce some difficulties in operation when used for a maximum hook speed of greater than about 15 ft. per min. However, if instead of point 1 we arrange for point *A* by connecting some resistance in parallel with the armature and some resistance in series with the armature and field, then it is a very simple and easy matter to obtain the desired creeping speed. In Fig. 7, point *A* is obtained by arranging the resistance so that at standstill 170 per cent of normal current flows from the line through the series field, and of this current, 136 per cent of the normal current flows through the armature; whereas when the motor is running with no torque at all, the voltage across its armature will be held down to 27 per cent of normal voltage by means of the shunted resistance across the armature. Curve point *A* shows that with a load requiring 100 per cent torque from the motor for hoisting and not over 137½ per cent torque to break static friction, a creeping speed of 7 per cent of normal speed can be obtained. On 50 per cent load, a creeping speed of 16 per cent can be obtained. If necessary, another curve lower in value than point *A* can be provided. This curve shows clearly two marked advantages for the direct current over the alternating current. First, a lower value of creeping speed can be obtained, and second, no especial skill or attention is required of the operator in order to obtain it. The controller is simply turned to the first point and left there without further attention.

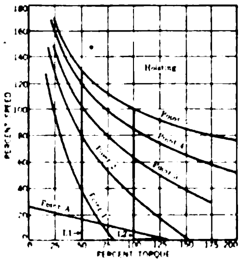


FIG. 7—SPEED-TORQUE CURVES OF DIRECT-CURRENT, SERIES-WOUND MOTOR WHEN CONTROLLED BY FOUNDRY-TYPE CONTROLLER—HOISTING SIDE

As mentioned in the first part of this paper, it is required for lowering either that a mechanical load brake be provided or that dynamic braking be used. Of course on an alternating-current motor it is possible to obtain regenerative braking—that is, when the motor is driven above synchronous speed it acts as a generator and retards the driving load. Such a motor, equipped with a substantial solenoid brake, would give desired maximum speed control of the crane, but would not give desired creeping speed control. With direct current it is possible to connect the motor for lowering so that any desired speed can be obtained uniformlly. Fig. 9 shows the connections of a controller arranged to give dynamic braking for lowering. Points 1, 2, 3, 4 and 5 in Fig. 7 show the speed-torque curves on points 1, 2, 3, 4, and 5 of the hoisting side of this controller. Points 1, 2, 3, 4, 5 and 6 in Fig. 8 represent the speed-torque curves on points 1 to 6 respectively on the lowering side of this controller. These latter curves show that when torque is required of the motor to drive the load downward each point of the controller will give a certain amount of torque; whereas should torque be required to hold back a falling load, this same point on the controller will give this required torque at a slightly higher speed. Consequently there is no danger of the load running away on any point.

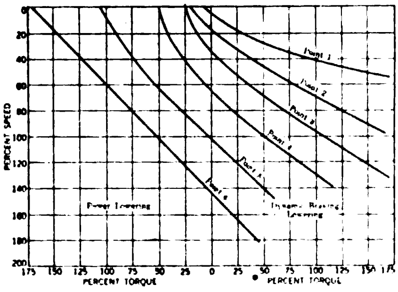


FIG. 8—SPEED-TORQUE CURVES OF DIRECT-CURRENT SERIES-WOUND MOTOR WHEN CONTROLLED BY FOUNDRY-TYPE CONTROLLER—LOWERING SIDE

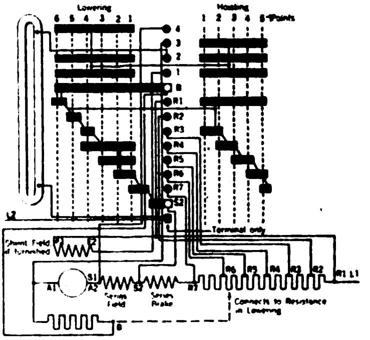


FIG. 9—CONNECTIONS OF CRANE HOIST CONTROLLER WITH DYNAMIC BRAKING ON THE LOWERING SIDE

Reviewing the above paragraphs, I would conclude by saying that for foundry service a careful arrangement of cranes should be made to accommodate the work in the best possible manner. The maximum hook speeds for the cranes should be chosen carefully and scientifically. For maximum hook speeds of 15 ft. per min. and less, ordinary rheostatic controllers are practically always suitable without very special precautions being taken to adapt them for foundry service. For maximum hook speeds above 15 ft. per min., it is sometimes necessary to go to special arrangements. On direct current, a convenient method is to use a shunting resistance across the armature for obtaining creeping speed. For alternating current, it is necessary to provide a larger number of controller points and sufficient resistance to reduce the torque at starting to about 25 per cent of normal torque. While it is true that direct-current gives a nicer and more convenient control for creeping speeds, yet alternating current provides good enough control for practically all cases. Where a foundry is large enough to admit the use of several different cranes, each having a different value of maximum hook speed, the shortcomings of alternating current disappear altogether in most cases. Even where only one or two varieties of cranes are used in a foundry alternating current may give entire success, provided most of the creeping speed work requires not less than 25 per cent of normal speed and only a small portion of the creeping speed work requires as low as 10 per cent of normal speed. The success of this latter arrangement depends largely on the excellency of the mechanical load brake, solenoid brakes and gearing which are furnished with the crane. Where alternating-current power is supplied by a power company, it is, therefore, rarely necessary to go to the extra expense of converting this power into direct current so as to accommodate foundry cranes.

As a basis of recommendation I would present, for the consideration of those present, the statement that alternating current is acceptable when used with a well built crane, a good solenoid brake and a good mechanical load brake under either of the following conditions:

First (a) When not less than 25 per cent of maximum geared speed is required for delicate operations.

(b) When torque to break static friction does not exceed running torque by more than 33 per cent: or

Second (a) When not less than 10 per cent of maximum geared speed is required for delicate operations.

(b) When torque required to break static friction does not exceed running torque by more than 25 per cent.

(c) When the time used up in performing delicate operations does not occupy more than 5 per cent of the total time of the operator.

I hope that the above statements will bring forth enough discussion to settle on rules which can serve as a guide.

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MILL CONTROLLERS

BY H. F. STRATTON

ABSTRACT OF PAPER

Electric power is largely supplanting all other types of power for steel mill work probably on account of its superior controllability. In almost any type of mill control the object is to start, stop and reverse the machine and its load in the shortest space of time, work done at constant speed being of minor importance. This leads to an investigation of the acceleration of motor-driven machines. The ratio gearing between the motor and the machine is one of the important factors influencing the time of starting and stopping the machines. Analysis is made of the effect of gear ratio between motor and machine, and equations are deduced from which can be calculated the best ratio of gearing for quick starting, quick stopping, or quick starting and stopping. While these equations may be used to determine theoretical limitations of speed and acceleration any deductions drawn from their use must necessarily be modified by practical considerations.

I PROPOSE to eliminate from discussion in this paper, controllers for: First, motors driving main rolls; second, motors on cranes or ore bridges, and third, motors operating skip hoists. This confines the subject to that class of controllers somewhat vaguely, but rather understandingly, designated as mill controllers. This caption will be taken to include controllers for the operation of hot metal mixers, charging machines, open hearth furnace doors, soaking pit covers, ingot buggies, mill tables of all descriptions, screw-downs, manipulators, shears, saws, furnace pushers, cooling beds, etc.

In the business of making steel there has never been a disposition to permit any unproved theoretical considerations to loom very large in comparison with proved practical operating methods. Any proposed system or method has been compelled quickly to establish its just claim to recognition or else promptly be discarded. So far is this statement meant from being a criticism, that I wish to say that I thoroughly believe the present practise in regard to mill controllers represents, to a high degree, a successful compromise between theory and practise, insofar as theory and practise may be considered conflicting.

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In a recent paper before the Association of Iron and Steel Electrical Engineers, Mr. Tschentscher said, "the hearty cooperation of manufacturer and user has resulted in the production of reliable electrical equipment, both for generation and utilization. Operation costs of such equipment are far below that of any other type of equipment. Moreover, quality of output and the quantity of the same has been greatly improved by the application of electricity in the iron and steel industry. Lastly, electrical equipment is now so arranged that the resulting installations tend to the promotion of the greatest comfort and safety to the working force, requiring a minimum tax upon its vitality. Electrical engineers in the iron and steel industry may well, therefore, look into the future for a larger demand upon their capabilities and for the development of their initiative and capacity to the utmost." In almost all writing purporting to deal in a comprehensive way with the manufacture of steel, one will find that electric drive is freely conceded as being a very important and probably indispensable factor in the rapid development of this industry to its present effective status. The effectiveness of electric power in a steel mill, is largely due to the fact that the equipment has been designed and built to meet the special requirements of steel mill work. It is significant that the phrase "mill type machinery" means without further explanation, machinery that will stand up to its work.

In a steel mill, electric power, considered merely as power, is no better than steam power or hydraulic power. Electric power has largely supplanted all other types of power probably because of its superior controllability. One man controls the operations of possibly three or four motors which start, stop, or reverse the ponderous machinery necessary for the manufacture of steel. These operations are performed with comparatively little physical or mental effort, they are duplicated in their most efficient form thousands of times each day, and they are so hedged around with protective devices that the hazard to men and machines has become astonishingly small.

The manufacture of steel is essentially a series process; the continuity of operation of each step hinges on the preceding and succeeding steps being performed regularly and on time; a slowing down of any important part of a mill is equivalent to slowing down the entire mill; the output of a five million dollar unit—and therefore the return on this investment—may be limited by the slowness of the screw-down of the blooming mill.

Of the entire time and work expended in a mill, a part is devoted to actual manipulation of the steel in heating, pouring, rolling, shearing, sawing, and finishing; this part is basic; it is itself the manufacture of steel; it may be improved, it cannot be eliminated. The other part of the work and time is devoted to the adjustment of machinery and conveying the steel from one operation to the next one; it consists, for instance, in the opening and closing of furnace doors and soaking pit covers, the transportation of the product by ingot buggies and tables, the adjustment of screw-downs and gages, the movements of manipulators. Such operations, although necessary, become waste time if they delay the real operations of heating, rolling, shearing, etc. This, in general, is the class of work to which mill controllers are applied. Their general specifications may be summed up by saying that it is taken as a matter of course if they operate satisfactorily day after day, but it is a matter of much comment if they cause a half hour's delay.

In almost any type of mill controller the main object is to start, stop, or reverse the machine and its load in the quickest feasible period of time. The work done at constant speed is of minor importance. I believe, therefore, that a general investigation and analysis of the acceleration of a motor-driven machine is a proper subject to be considered in this paper.

In the ensuing discussion of the acceleration of a motor and its load, the entire work performed by the motor will be considered to be of only two kinds, viz., the inertia load and the work load. The inertia load will be taken as the number of foot-pounds necessary to make any selected change in the rotary or linear velocities of all bodies moved by the motor, including its own armature; this is exclusive of any work done against friction or in lifting any weights against gravity; it is in short what is known as the flywheel load. The work load will be taken as as the sum of all the other amounts of work necessary for driving the machine; it will be represented for the most part by the friction of the machinery, but in some machines the lifting of weights against gravity will be a part of the work load.

During the process of acceleration of a motor, the torque developed by the motor is, of course, governed solely by the motor current, the high and low values of which are governed by the controller. When full line voltage has been applied to the motor, the torque is still dependent upon the motor current, but the motor current is now determined, first, during that time in which the motor speed is increasing, by the work load and the inertia load, and second, during the later period of relatively high and constant speed, mainly by the work load.

In other words, in the complete acceleration of a machine driven by a series or compound-wound motor, there are two stages through which motor and machine must pass before they attain a situation of even instantaneous stability.

The first stage begins when the armature and the starting resistance are connected to the supply lines and ends when the starting resistance has been completely short circuited and the armature is receiving full line voltage. As the great majority of mill controllers are of the magnetic-switch current-limit type, manual controllers will not be considered. The initial current peak is determined and limited by the starting resistance, and is generally approximately 150 per cent of rated full-load motor current. The first and all valley currents are determined and limited by the operation of series current relays or magnetic switches. All following peak currents are determined and limited by the successive sections of resistance permitted to remain in series with the motor. The time and the mode of variation between each peak current and its succeeding valley current, are governed by the relation between developed motor torque and work and inertia loads. With the usual magnetic switch controller peak currents may be assumed roughly to be 150 per cent, and valley currents 100 per cent, of rated full-load motor current. The average shape of the current-time curve between peaks and valleys may be approximated; it curves downward so that the average is somewhat less than half the sum of the peak and valley currents. If the characteristics of the motor are available it is possible to make a fairly accurate determination of the average developed motor torque during this first stage. With any given machine and driving motor, the inertia load is precise and definite; it is the sum of the number of foot-pounds that must be imparted to each rotating element to bring it to its final speed; in each case it is the product of a constant $\frac{2\pi^2}{g}$, the moment of inertia (weight $\times$ square of the radius of gyration), and the square of the number of revolutions per second which is finally attained. The amount of inertia load which is absorbed by any rotating member in attaining any definite speed of rotation is independent of the time but is directly dependent upon the speed attained. The time, however, varies inversely with the driving torque.

Let T = torque tending to rotate a body without friction;
N = final speed of rotation of body;
I = moment of inertia of body;
t = time required to accelerate from rest to speed N;
C = a constant.

Then;

$$t = \frac{C\,I\,N}{T}$$

The work load is indefinite and may vary at different speeds. On a mill table, it certainly increases if the bearings are tight, if the grease is cold, or if the rolls are warped by excessive heating.

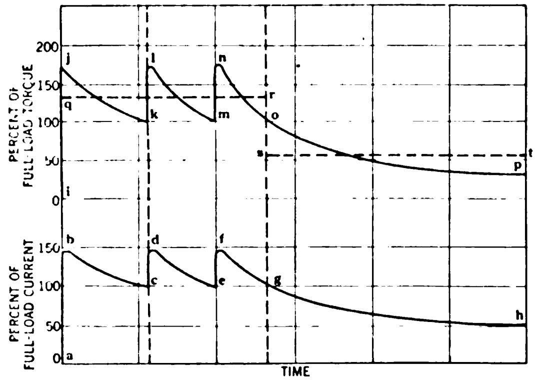

FIG. 1

The second stage begins when full line voltage is applied to the armature, and ends when the developed motor torque equals the torque of the work load. As long as the motor torque is larger than that of the work load, the surplus of motor torque is devoted to a further increase in speed.

Fig. 1 is a graphical representation of the variation in motor current and motor torque as they occur in the acceleration of a motor-driven machine from rest to a speed at which the work load is equal to the developed torque. In the diagram of Fig. 1, the horizontal axis represents time, and the vertical axis represents, in the case of the lower curve, motor current, and in the case of the upper curve, developed motor torque. Considering first the current curve, when the line switch is closed at *a*, the current quickly rises to the peak at *b*, and the motor starts to accelerate, the current dropping until it has reached approximately full load value. The first accelerating switch is supposed to close at *c*, giving the peak *d*, after which the current again drops to full load value as at point *e*. Another accelerating switch is here supposed to close, giving the motor armature full voltage which results in the peak *f*. The occurrences from the point *a*, to the point *f* collectively, form what has already been called the first stage of acceleration in the motor. It is convenient to extend this stage to the point *g*, which might be described by saying that it is that instant of time when the motor current has dropped to its full load value, and when, therefore, the motor has attained normal full-load rated speed. From the point *g* to *h*, the current is constantly diminishing, due to a further acceleration of the motor and its load, until, at the point *h*, the motor torque has diminished to such an extent that it is equal to that of the work load. The current passing through the motor when it has reached a state of constant speed, has been assumed here to be one-half of full-load current. I have selected this value of motor current because it is approximately the percentage of full-load motor current which I have frequently found would be taken by a motor driving a mill table, providing the table is allowed to run continuously in one direction. In the case of an ordinary series mill motor, this would mean a speed of about 50 per cent greater than normal, and while I realize that many motors driving mill tables would attain speeds much higher than this, yet this figure will be representative enough to serve present purposes.

The upper curve *i*, *j*, *k*, *l*, *m*, *n*, *o*, *p*, indicates the variation in motor torque which, of course, in the case of a series motor, varies at a more rapid rate than the motor current. In other words, when the motor current varies from full load to 50 per cent overload, the motor torque varies from full load to about 75 per cent overload. Correspondingly, when the motor current has dropped to about one-half full-load, the motor torque is about one-third full load. The horizontal dash line *qr*, is the average motor torque developed during that portion of the acceleration of the motor which begins when the line switch is closed and ends when the motor armature attains normal full load speed with full voltage applied. The horizontal dash line *st*, represents the motor torque developed during the balance of the acceleration and ending when the speed of the motor has become constant.

Any factor that prominently influences the time of starting and stopping mill machinery, is worth investigating. The ratio of gearing between motor and machine is such a factor and is one of decided importance. This has been guessed at ever since motors were used in a mill. On identical machines in different mills—and sometimes in the same mill—this ratio of gearing has varied 10 to 1. In an experience with a good many hundred mill controllers, I have seen more troubles traceable to poorly selected ratios of gearing than to any other single cause.

The balance of this paper, will be an attempt to analyze the effect of the ratio of gearing between motor and machine, and to determine what this ratio should be to give the quickest starting and stopping.

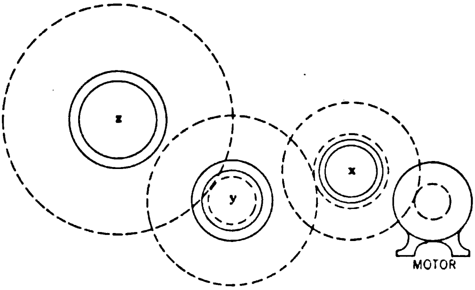

FIG. 2

Fig. 2 represents diagrammatically any typical mill machine and its motor. Besides the armature shaft, there are three shafts x, y, and z. The dotted circles indicate gearing and the solid circles indicate the weights rotating on each of the shafts x, y, and z. Let these weights be designated respectively W_x, W_y, and W_z and let their corresponding radii of gyration be called k_x, k_y, and k_z. Then their moments of inertia are as follows:

$$I_x = W_x k_x^2$$
$$I_y = W_y k_y^2$$
$$I_z = W_z k_z^2$$

Let r_x = ratio of gearing between shaft x and armature, so that the armature rotates r_x times as fast as shaft x;

r_y = ratio of gearing between shaft y and shaft x; and,

r_z = ratio of gearing between shaft z and shaft x.

Then if shaft x is revolving at a speed of S revolutions per second, the speed of shaft $y = \frac{S}{r_y}$, and the speed of shaft $z = \frac{S}{r_z}$.

The inertia load of any rotating member equals $\frac{2\pi^2}{g}$ times its moment of inertia, times the square of its speed. Therefore if the entire system is rotating at such an angular velocity that the speed of the shaft x is S revolutions per second, the inertia load of the shafts x, y, and z is as follows:

$$\text{Inertia load} = \frac{2\pi^2}{g} S^2 I_x + \frac{2\pi^2}{g} \cdot \frac{S^2}{r_y^2} I_y + \frac{2\pi^2}{g} \cdot \frac{S^2}{r_z^2} I_z$$

$$= \frac{2\pi^2 S^2}{g} \left(I_x + \frac{I_y}{r_y^2} + \frac{I_z}{r_z^2} \right)$$

This inertia load would be identically the same if we had the condition shown in Fig. 3, where the moment of inertia of the shaft x is supposed to have been increased from I_x, to

$$I_x + \frac{I_y}{r_y^2} + \frac{I_z}{r_z^2}.$$

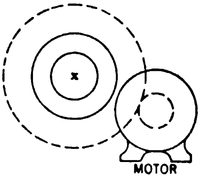

FIG. 3

In other words, so far as the inertia load of a machine is concerned, it may be considered concentrated on any one selected shaft, providing the moment of inertia of the member on each other shaft is divided by the square of the ratio of gearing between that shaft and the selected shaft. Or it may be stated that the equivalent moment of inertia of one revolving part, at the center of rotation of another revolving part to which it is geared, is inversely proportional to the squares of the respective speeds of rotation of the two parts.

Referring back to Fig. 2, assume that on shaft x, there is a load torque of F_x pound-feet; on shaft y, one of F_y pound-feet; and on shaft z, one of F_z pound-feet.

If shaft x, makes N revolutions, shaft y makes $\frac{N}{r_y}$ revolutions, and shaft z makes $\frac{N}{r_z}$ revolutions.

Then

$$\text{Work load} = 2\pi N F_x + 2\pi N \frac{F_y}{r_y} + 2\pi N \frac{F_z}{r_z}$$

$$= 2\pi N \left(F_x + \frac{F_y}{r_y} + \frac{F_z}{r_z} \right)$$

It is apparent that the work load would be the same with the conditions of Fig. 3, providing the load torque of shaft x is supposed to have been increased from F_x, to $F_x + \frac{F_y}{r_y} + \frac{F_z}{r_z}$

In other words, so far as the work load of a machine is concerned, it may be considered concentrated on any one selected shaft, providing the load torque of each shaft is divided by the ratio of gearing between that shaft and the selected shaft.

The significance of these two laws is that we may consider any piece of mill machinery—for instance a roller table or a screw-down—as being mathematically the equivalent of a body having a certain moment of inertia and a certain load torque, both the moment of inertia and the load torque being considered to be concentrated on one shaft. This shaft may conveniently be assumed to be the one to which the motor is geared and it will be assumed that this shaft carries a weight having a moment of inertia equal to the sum of the equivalent moments of inertia of all parts of the machine and that a load torque acts on this shaft equal to the sum of the equivalent load torques of all parts of the machine. There is nothing uselessly complicated in these assumptions; on the contrary, they permit the use of simple computations instead of some very intricate ones. In the following discussion a mill machine will be considered as a motor geared to a shaft carrying a weight having the equivalent moment of inertia of the entire machine and acted on by the equivalent load torque of the entire machine. In short we have the conditions shown in Fig. 3.

Let I_1 = moment of inertia of machine
I_2 = moment of inertia of armature
N = number of revolutions to be made by machine
r = ratio of gearing of machine to motor
T = mean torque developed by motor, in pound feet
t = time of acceleration in seconds
F = load torque of machine.

The total work done by motor while the machine makes N revolutions

$$= 2\pi TrN \tag{1}$$

The total work done against the load torque while the machine makes N revolutions

$$= 2\pi FN \tag{2}$$

The average speed of rotation of the machine is $\frac{N}{t}$; hence its final speed of rotation is $\frac{2N}{t}$

Similarly, the final speed of rotation of the armature is $\frac{2rN.}{t}$

The inertia load of the motor is

$$\frac{8\pi^2 I_2 r^2 N^2}{gt^2} \tag{3}$$

Similarly, the inertia load of the machine is

$$\frac{8\pi^2 I_1 N^2}{gt^2} \tag{4}$$

Now, if the machine starts from rest and makes N revolutions, (1) = (2) + (3) + (4)

$$2\pi TrN = 2\pi FN + \frac{8\pi^2 N^2}{gt^2} (I_1 + I_2 r^2) \tag{5}$$

From (5), we get

$$t = \sqrt{\frac{4\pi N (I_1 + I_2 r^2)}{g (Tr - F)}} \tag{6}$$

Equation (6) then indicates the length of time required to start from rest and move the machine any definite distance corresponding to N revolutions. The following important deductions can be made from equation (6).

A. Since the current is proportional to the motor torque T, the power input is proportional to Tt; in other words, the kilowatt-hours necessary to move the machine any number of revolutions, is least when the time, t, is a minimum.

B. On the same basis of reasoning the heating of the motor is least when the time, t, is a minimum.

C. The time of acceleration, t, increases as the square root of the number of revolutions, *i. e.*, $\sqrt{N}$.

D. Increasing the moment of inertia of either the machine or armature, increases the time, t.

E. Increasing the motor torque, T, decreases the time, t.

F. Increasing the load torque F increases the time, t.

G. Tr must always be greater than F, or t will be infinite; in other words, the motor would never accelerate.

The ratio of gearing, r, enters into the equation in a manner not simple enough to permit of the determination of its effect by inspection. To determine what should be the value of r in order that t may be a minimum, the differential of t with respect to r is equated to zero. Omitting the various steps of the calculus, the following equation is obtained:

$$r = \sqrt{\frac{I_1}{I_2} + \left(\frac{F}{T}\right)^2} + \frac{F}{T} \tag{7}$$

By the use of equation (**7**) and knowing the moments of inertia of machine and armature, the motor torque and the load torque of the machine, that ratio of gearing, r, may easily be determined, which will cause the machine to make N revolutions in the shortest time. It is to be noted as important, that N does not appear in equation (**7**). In other words, this most favorable value of r as determined by equation (**7**), is the same, no matter how many revolutions are made by the machine.

The equations (**1**) to (**7**) inclusive, relate to the condition of the machine starting from rest and making N revolutions. Of equal importance is the condition that the machine, when running at any speed. should be brought to rest in the shortest time by reversing the current through the armature.

Let I_1, I_2, r, T and F have the same significance as in the case of acceleration of the machine. In addition let

t_1 = time of stopping in seconds.
S = speed of machine in revolutions per second when motor is reversed.

The inertia of the machine

$$= \frac{2\pi^2}{g} I_1 S^2 \tag{8}$$

The inertia of the armature

$$= \frac{2\pi^2}{g} I_2 r^2 S^2 \tag{9}$$

The average speed of the machine in revolutions per second $= \frac{S}{2}$. Therefore, the machine makes $\frac{St_1}{2}$ revolutions before coming to rest. Similarly the armature makes $\frac{Srt_1}{2}$ revolutions before coming to rest.

The total work done by the motor while bringing the machine to rest, from a speed S,

$$= \pi TSrt_1. \tag{10}$$

The work load of the machine assisting the motor in bringing the machine to rest

$$= \pi FSt_1. \tag{11}$$

Then (**8**) + (**9**) = (**10**) + (**11**)

$$\frac{2\pi^2 I_1 S^2}{g} + \frac{2\pi^2 I_2 r^2 S^2}{g} = \pi TSrt_1 + \pi FSt_1 \tag{12}$$

From (**12**) we get

$$t_1 = \frac{2\pi S\ (I_1 + I_2 r^2)}{g\ (Tr + F)} \tag{13}$$

Equation (**13**) indicates the length of time required to bring a machine to rest from a speed S, by reversing the current through the armature. As in the case of acceleration, the following deductions can be made by inspection:

A. The power input in the motor is a minimum when the time of stopping, t_1, is a minimum.

B. The heating of the motor is least when t_1 is a minimum.

C. The time of stopping varies directly as the speed, S, of the machine.

D. Increasing the moment of inertia of either armature or machine, increases the time, t_1.

E. Increasing the motor torque, T, decreases the time, t_1.

F. Increasing the load torque, F, decreases the time, t_1.

As before, the differential of t_1 with respect to r, is equated to zero to determine that ratio of gearing, r, which will give the quickest stopping. This value follows:

$$r = \sqrt{\frac{I_1}{I_2} + \left(\frac{F}{T}\right)^2} - \frac{F}{T} \tag{14}$$

Note that this value of r involves the same quantities that enter into equation (**7**) and that it is independent of S.

We have now determined two values of r from equation (**7**) and (**14**). That of equation (**7**) is for quickest starting from rest and making any number of revolutions; that of equation (**14**) is for quickest stopping from any speed of rotation. It would be possible to make another determination to give the value of r for quickest starting plus quickest stopping. It is not possible to say whether quick starting or quick stopping is of the most general importance; also it is not true that a motor is reversed every time it is started. It seems reasonable, therefore, to assume that the most favorable value of r would be the arithmetical mean of the two values as determined by equations (**7**) and (**14**).

This gives the value of the ratio of gearing, r, as follows:

$$r = \sqrt{\frac{I_1}{I_2} + \frac{F^2}{T^2}} \qquad \textbf{(15)}$$

It is next in order to make some practical use of the equations. Assume that it is desired to investigate the ratio of gearing of some motor driven machine, say a mill table. For any standard mill motor it is easily possible to secure the weight, W, of the armature and its radius of gyration k,k being expressed in feet.

Then $$I_2 = Wk^2 \qquad \textbf{(16)}$$

Preferably adjust the controller to give peak currents of 150 per cent full load and valley currents of 100 per cent full load. The rated full-load current of the motor can be determined from the speed-torque curves of the motor. Connect a recording ammeter in the motor circuit, accelerate the motor from rest and allow the motor to run until the motor current has become constant. From the speed-torque curves of the motor, determine the torque at the motor in pound-feet corresponding to the constant motor current; let this torque be called H

Then, $$F = rH \qquad \textbf{(17)}$$

where r represents the existing gear ratio.

On the record made by the recording ammeter, note accurately the point where the motor has dropped to exactly full-load value after full line voltage has been applied to the motor. In other words, this is the point where the motor current reaches full-load value after the last accelerating switch has closed, and is indicated by g in Fig. 1. Measure accurately on the record the time between the closing of the line switch and the point g. This interval of time is t. From the speed-torque curves of the motor and the current record, determine the average torque developed by the motor during the interval of time beginning when current first passes through the armature, and ending when the motor current drops to full-load value after full line voltage has been applied to the armature. In other words, determine the average torque developed by the motor during the interval of time t. This torque is T and is expressed in pound-feet.

From the speed-torque curves of the motor, determine the speed of the armature at the point g. Let this speed be called P, which should be expressed in revolutions per second. If the armature starts from rest and reaches a speed of P revolutions per second, its average speed during this time of acceleration is $\frac{P}{2}$ revolutions per second. The total number of revolutions made by the armature during the time t, and rotating at an average speed of $\frac{P}{2}$ revolutions per second is obviously $\frac{tP}{2}$

Therefore

$$N = \frac{tP}{2r} \tag{18}$$

Equation (**5**) may be solved for I_1 as follows:

$$I_1 = \frac{2.56\ (Tr - F-)\ t^2}{N} - I_2 r^2 \tag{19}$$

I, r, F, t, N, and I_2 are all known, and the moment of inertia of the machine, I_1, can easily be determined by inserting these values in equation (**19**).

Equations (**7**), (**14**), and (**15**), can be solved for r when T, I_2, F, and I_1 are known. The determination of T has been explained; I_2, F, and I_1, are respectively obtained from equations (**16**), (**17**), and (**19**). If quick starting is of major importance, r can be determined from equation (**7**). If quick stopping is the chief consideration, r should be determined by the use of equation (**14**). On the other hand if quick starting and quick stopping are of approximately equal importance, equation (**15**) should be used.

A more comprehensive study of the question would be to determine by the use of equations (**6**) and (**13**), different values of t and t_1, corresponding to different assumed values of r, and then to plot curves between r, t, and t_1. These are shown in Fig. 4 where curve A, represents different values of t_1 for different values of r and curve B represents different values of t for different values of r. Curve C is obtained by adding the ordinates of curves A and B, and therefore shows, for different values of r, the time of starting plus the time of stopping. Curve A is a minimum on the line aa, curve B on the line cc and curve C on the line bb. For any ordinary piece of mill machinery, the position bb would probably indicate the most favorable value of r.

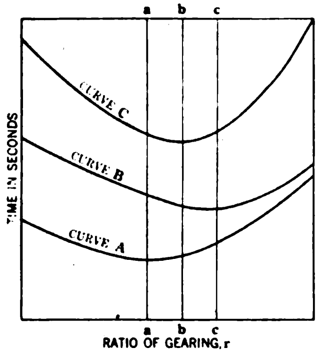

FIG. 4

To illustrate the practical application of these equations, a certain motor-driven mill table will be selected, concerning which I happen to have the necessary data. On Fig. 5, is shown the current-time record, and on Fig. 6, are shown the speed-torque curves of the motor.

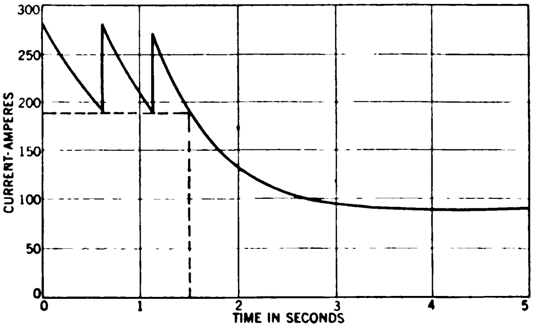

FIG. 5

From Figs. 5 and 6, it is found that

$$t = 1.5 \text{ seconds}$$
$$T = 630 \text{ pound-feet}$$
$$H = 150 \text{ pound-feet}$$
$$P = 9.5 \text{ revolutions per second}$$

It is known that the weight of the armature is 900 pounds and its radius of gyration is 0.55 feet. Therefore $I_2 = 900 \times .55^2 = 272.3$

Since $r = 5$, we have $F = rH = 5 \times 150 = 750$

From equation (**18**), $N = \frac{tP}{2r} = \frac{1.5 \times 9.5}{2 \times 5} = 1.425$

Inserting these values in equation (**19**) and solving, we find that $I_1 = 2892$.

By using the values of I_1, I_2, F and T in equation (**15**) we find that $r = 3.46$ would be the best ratio of gearing for quick starting and stopping.

It certainly should not be assumed by any one, that the use of these various equations, constitute a sufficient solution of the problem of determining the most favorable ratio of gearing for any particular motor-driven machine. The equations must be regarded merely as a theoretical analysis of the various factors entering into the question and any deduction drawn from their use, must necessarily be modified by local conditions and practical considerations. For instance, it would be foolish to accelerate or retard a mill table so rapidly that the steel would slip on the rolls or that handy control would be lost. Furthermore, due to variations in friction, the work load may change from day to day or from hour to hour, so that some assumption must be made as to its average value. In short, this is no hair-splitting subject; on the other hand, it is believed that a judicious application of theory to practise, will in this case, lead to results which will prove to be substantial and worth-while improvements.

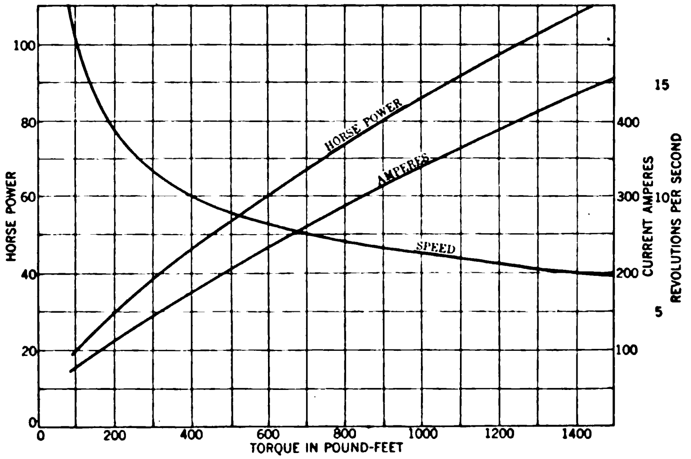

Fig. 6

To be presented at the 308th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 15-16, 1915.

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THE ALTERNATING-CURRENT COAL HOIST

BY RAYMOND E. BROWN

ABSTRACT OF PAPER

The paper describes an alternating-current coal hoist recently installed near Pittsburgh in which dynamic braking is employed. The brakes and clutches are operated by compressed air which permits of a maximum rate of operation and also makes feasible the uses of various safety devices.

The electrical equipment of the coal hoist must be capable of continuous operation at the maximum speed and any attempt to insure against motor or brake trouble by providing excess capacity simply results in the motor being operated at that increased capacity. The control in lowering the empty bucket at high speed must be accurate enough so that it can be slowed down quickly without damaging the barges or steamers in landing. With a friction brake the only way to avoid striking too hard in landing is to make a complete stop before reaching the bottom thereby causing an appreciable loss of time which is entirely avoided by the use of dynamic braking. In the case of the plant described the control has proved sufficiently accurate and exact so that a complete cycle of the hoist trip due to the overlap of hoisting and racking movements can be made in 40 seconds instead of the estimated time of 50 seconds.

THE coal hoist, and of course the ore-handling bridge or unloader, is different in several respects from most other machines for hoisting or transferring materials, and also from nearly all other applications of electric or steam power.

One of the points of difference is in the necessity for a very accurate analysis of the cycle of operation, in order to obtain a motor of the proper speed, torque and heating capacity. In the case of a motor handling any material in its progress through the mill, the amount of work it will have to do is, to some extent at least, determined or limited by the apparatus which brings the material to it or takes it away to the next operation. Consequently, by providing some excess over the rated capacity, the motor can be given what we may speak of as a factor of safety against overheating. In the case of the hoist, however, the material in front of it is, we may say, unlimited, as it is usually brought in in quantities sufficient to permit the hoist to operate at its maximum possible speed for a period long

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enough to cause any trouble that can arise from overheating of either the electrical or mechanical parts.

The electrical equipment consequently must be capable of continuous operation at the maximum speed which the weight lifted, the motor characteristics and the operators movements will permit. Any attempt by the designer of the hoist to insure against motor or brake trouble by providing an excess in capacity over and above that specified by the purchaser simply results in the machine being operated at that increased capacity as long as any material remains in front of it.

One other point wherein the coal or ore hoist differs from other hoists is in the lowering of heavy unbalanced loads at high speeds and yet under very exact control. The furnace or skip hoist when not counterbalanced approaches this condition, but on account of working between fixed points it can have limit switches to provide for the slow-down and stop. The coal or ore-hoist on the other hand has no fixed elevation for the material which it is digging, consequently it is still necessary for the operator to control the lowering of the bucket. The ladle crane lowers its full load, but its speed is very low. The coal or ore hoist must lower an empty bucket weighing from one-half to two-thirds as much as the load hoisted, and must do this at a speed from 300 ft. (91.5 m.) per min., to 500 ft. (151.5 m.) per min. The operator's control over this speed must be accurate enough so that he can quickly slow the bucket down to land it on the frail wooden barges used on our rivers or on the comparatively thin steel plating of the lake steamers.

The statement has been made, and probably is still believed by some, that the friction brake, operated by foot or hand, is the most reliable control for lowering a bucket. With dynamic braking, each notch on the controller gives a uniform lowering speed, and since the load being lowered is always the same, it follows that the speed on any given point is always the same. On the other hand, no uniform pressure or position of a foot brake can fail either to retard the load or permit it to accelerate, because even if the operator does accidentally produce a torque exactly balancing that of the load, the coefficient of friction changes as soon as the brake temperature rises, and consequently the balance is destroyed as soon as it is established. A speed variation of 20 per cent produces a change of 44 per cent in the kinetic energy of the moving masses, and this must be absorbed by the brake. Since the operator can not estimate the speed within 20 per cent and has no means of producing any definite speed while lowering with a friction brake, it is evident that the only way to avoid striking too hard is to make a complete stop before reaching the bottom. This causes an appreciable loss of time which is entirely avoided when dynamic braking is used. It is unnecessary to dwell at any length on the effect on the machinery and ropes of the shocks caused by sudden applications of the brakes, or on the expense of replacing the brake lining and occasionally the brake wheels.

Reference was made earlier in this paper to the question of heat-absorbing or rather heat-radiating capacity of motors and brakes. Another of the advantages of dynamic braking is that the heat-capacity of motors seems to be capable of more accurate determination, or at any rate, is more accurately determined than is the case with the ordinary friction brake, as it has not been a very rare occurrence for a friction brake to require some changes before it would lower the bucket on a high-speed hoist without overheating.

The purpose of this paper is to describe (to some extent from an operative view point) a coal hoist recently installed for the Union Railroad near Pittsburgh. This is a duplex tower containing two independent hoists taking coal from river barges and loading it into railroad cars. The coal can be crushed and screened into various sizes or may be loaded direct without any preparation. The entire plant is operated by 220-volt, 25-cycle, three-phase a-c. motors.

The two engines for handling the buckets are located in a room about 28 ft. (8.5 m.) by 42 ft. (12.8 m.) at the top of the tower. Below this are the trolley tracks, which extend out over the river as a fixed boom or cantilever. Below these tracks in the tower is the coal hopper, which is provided with two discharge spouts. The mechanism below this point, like that above the hopper, is in duplicate, so that a description of one side will suffice.

When the coal is to be crushed it is conveyed to the top of the crusher by a pan feeder conveyor driven by a $7\frac{1}{2}$ h.p. motor. The crusher is driven by a belt from a 150-h.p. 480-rev. per min. motor which has an auto-starter with separate transformer, and is protected by a three-pole a-c. contactor-type circuit breaker with push buttons for resetting overload and for closing the circuit breaker.

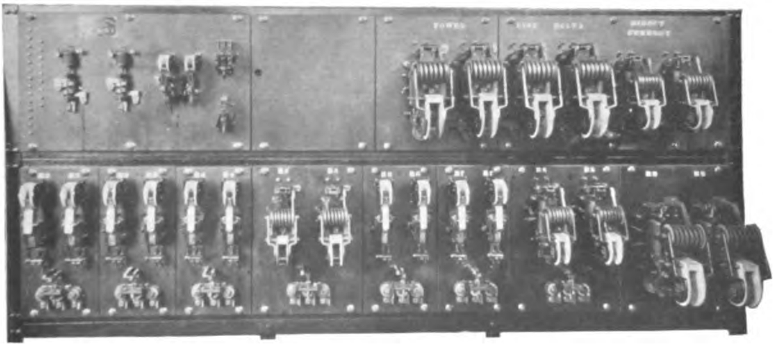
The crusher delivers to a set of shaking screens, operated by eccentrics on a shaft driven by a 25-h.p. motor. When it is not necessary to crush the coal, it is fed by another type of feeder directly from the hopper to the shaking screens.

The auto-starters and circuit breakers for the motors driving the feeders and shaking screens on both halves of the plant are grouped together at a point where the attendant can see the coal passing into the cars, and he can, by pressing a button, stop the flow of coal to either of the cars. As the shaking screens in the two sides of the tower deliver to different tracks, the simultaneous loading of orders for different grades of coal is possible.

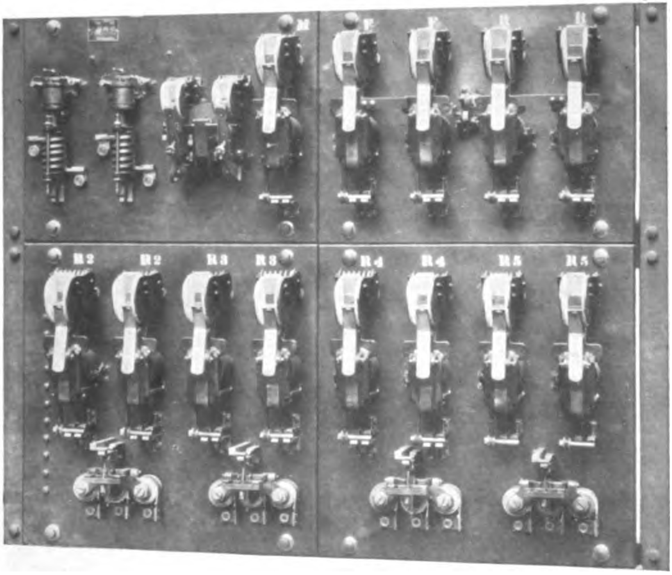
The bucket has an average capacity of 4 short tons (3650 kg.) and weighs about 11,000 lb. (5000 kg.). The closing rope passes around sheaves in the top of the bucket and in the vertically moving crosshead which is connected to the spades to give the necessary power for closing them. The ends of this rope pass over sheaves in the trolley, then to sheaves at the ends of the trolley track and to the closing drum in the engine room. The hold rope, which carries the open bucket, passes under a sheave in the top of the bucket and follows the same route as the closing rope, both ends being anchored on the hold drum. The hoist motor is connected to these two drums through two pairs of gears having a total ratio of 10 to 1, which gives the bucket a speed of 7½ feet (2.3 m.) per second. Each drum has an air-operated clutch, and there are two air-operated band brakes, one being on the hold drum and the other on the intermediate shaft or countershaft next to the motor. The operator has a valve for each clutch, and one for the two brakes. The construction of this valve is such that a partial movement of the handle applies the hold brake, and a complete movement applies both.

The rope arrangement is such that the trolley or racking movement is independent of the bucket engine. The rack engine consists of a 75-h.p. mill-type motor geared to a drum from which ropes lead to the two ends of the track and thence to the trolley. The drum is provided with an air-operated brake. The motor is controlled by a plain reversing contactor-type controller, with master controller in the operators cab. This master controller, as well as that for the hoist, has a straight line bevel-gear drive handle, so that the movements of the handles of the two controllers and the four air valves are all of the same character.

It may be of interest to follow out a cycle of operations, starting at the time when the bucket is ready to begin lowering. The hold brake valve is moved to the release position, and the hoist



HOIST CONTROLLER PANEL [BROWN]



RACK CONTROLLER PANEL [BROWN]

controller handle is placed on the point which has been found to give the desired speed. The bucket descends at a uniform speed, and if the coal is deep enough to prevent injury to the boat, the speed is not checked until just before the bucket strikes the coal, when the controller handle is moved to the maximum braking position and the brakes are also applied. When working near the bottom of the boat, the increased dynamic braking is applied earlier, so as to land the bucket without shock. The hold clutch is now released with the left hand while the right moves the controller handle to the proper point for closing. When the bucket is closed the left hand returns the clutch valve handle to its application position, while the right applies full power for hoisting. The left hand is now free to rack the trolley in toward the hopper at the proper time. When the bucket is high enough, the hoist controller is returned to its off position, and as the bucket slows down the hold brake is applied. The bucket by itself would stop its upward motion in about a foot (0.3 m.), but the momentum of armature, gears and drums is sufficient to hoist it several times this amount after the power is shut off.

The bucket is dumped by releasing the hoist clutch, which is applied as soon as the bucket is open. During this time, the left hand is stopping the trolley and racking it out again. If followed out closely this cycle will be found to require only six changes in the position of the operator's hands—that is, six shifts from one handle to another.

All of the handles move in vertical planes toward and away from the operator, and none of them require any appreciable effort.

This system of bucket engine construction permits the use of one motor when the necessary amount of power is available in one unit, and permits the use of two or even more motors if necessary, without any change in the scheme of operation. It allows the full power of hoist motors to be used for the final closing of the bucket where the material being handled is such that this amount of power can be utilized. It also permits the full torque of hoist motors to be used for retarding the speed of the bucket while lowering. In cases where the necessary amount of power can be obtained in one motor, the cost of motor and controller will be considerably less than where the type of engine requires two motors and two controllers. Also, when the hoist is so large that two motors are necessary, the cost of the controller equipment is less if the two motors are handled by one controller than where two separate controllers are needed. Where the two drums are independent, each having its own motor and controller, lowering requires the manipulation of two handles instead of one, as one motor must pay out the slack closing line while the other acts as a brake.

The use of air for operating brakes and clutches permits the operator to maintain the maximum rate of operation throughout the day, to a much greater extent than can be done where the severe labor of manipulating clutches and brakes by hand or foot is required of him, especially when handling heavy loads. It also makes it feasible to install various safety devices. In this plant the hold brake is automatically applied if the bucket is hoisted too high, also when the overload relay cuts off the power to the motor, and in case of loss of voltage on either the a-c. lines or the d-c. control circuit. Limit switches on the trolley track cut off power to the rack motor and apply the air brake on the drum.

A small motor-generator set is located in each half of the engine room, supplying 220 volts direct current from a six-kw. shunt-wound generator for the coils of the contactors on the hoist and rack controllers. It also excites the fields of the other generator, a nine-kw. 15-volt compound-wound machine, which supplies the low-potential direct current to the stator windings of the hoist motor during dynamic braking. These two generators are direct connected to a 20-h.p. 70-rev. per min. a-c. motor.

Air is supplied by a two-cylinder compressor driven by an a-c. motor. The compressor governor is arranged to lift the inlet valves in the cylinder heads instead of stopping the motor as is customary in d-c. operation.

The hoist engine is driven by a wound-rotor induction motor with an intermittent rating of 315 h.p. The calculated cycle of operation includes six seconds closing at 150 h.p., three seconds accelerating hoist at 425 h.p., eleven seconds hoisting at 340 h.p., and twelve seconds lowering, at 130 h.p. braking. These values are for power at the motor pinion.

The hoist controller consists of the master switch in the operators cab, and a panel in the engine room, with the necessary resistance located immediately behind the panel. The panel carries the necessary contactors interlocks and relays. There are three single-pole contactors to connect the stator windings to the a-c. lines; one contactor to open the stator windings at one point and two contactors to connect the d-c. lines from the 15-volt generator to the stator when this delta switch is open. Each step of resistance with its pair of contactors makes a star connection between the three busbars connected to the slip rings on the rotor. Resistance is reduced by adding more steps in parallel with the first, and the last step is a short circuiting contactor. There are five steps in accelerating the hoist, and four points of dynamic brake control. Each of the accelerating switches except the last is provided with an individual accelerating relay. The panel also has no-voltage relays in the a-c. and the 220-volt d-c. circuits, and two overload relays.

On the lowest floor of the tower is located a large shifter engine, consisting of two drums with clutches and brakes geared to a 30-h.p. motor. This is controlled by a face-plate reversible controller, and the brakes and clutches are hand-operated. Ropes pass along the face of the dock and around sheaves and are attached to the barge which is being unloaded.

The beginning of actual operation of this plant was looked forward to by its builders with considerable interest and possibly some anxiety. The speed was to be 50 per cent higher than had been previously used in any a-c. hoist with dynamic braking, and there had been rumors that the controller designers had encountered some very difficult problems in working out the control. When the first a-c. hoists with dynamic braking were built in 1909, they required a considerable period of adjusting and a number of changes. On account of the higher speed of this hoist, and as this control was being developed by another company, the builders of the hoist were naturally anxious as to the results that might be obtained.

The control equipment had been checked over by a representative of the controller company, and on the day that coal was to be hoisted he and the writer were present to see what would happen. One accelerating relay on the hoist panel required a slight adjustment to smooth out a peak which occurred when the last contactor closed, and a similar adjustment was made on the rack controller. It was not found necessary to make any change in the amount of resistance in any of the various steps, and except for the adjustments mentioned, which required only a few minutes time, the controller is operating exactly as sent from the factory.

As to the accuracy of control over lowering, it may be sufficient to say that the maximum speed is higher than the hoisting speed, and the minimum is low enough to land the bucket on the thin planking of the river barges without perceptible shock. In spite of the wide range in lowering speed, and the small number of steps on the dynamic braking control, the handle may safely be thrown to the maximum braking position while the bucket is descending at its maximum speed. The use of separate contactors for braking permits their accelerating relays to be adjusted so that the torque on the motor will not be brought above the pull out point.

As a result of the exact and accurate control which the operator has over the bucket movements, this hoist has shown itself to be capable of continued operation on a somewhat shorter cycle than was estimated. This is due to a large overlap of hoisting and racking movements, and a slightly higher lowering speed. While the cycle necessary to make the required capacity was 50 seconds, the hoists can make trips in 40 seconds.

A few words in regard to the first application of dynamic braking to a-c. hoists on a large scale may be of interest. A number of five-ton coal bridges were built by the same company about six years ago for several coal docks in Superior, Wis. The buckets were larger than any previously used for unloading coal from lake boats, and the speeds were higher. The use of friction brakes for lowering the buckets was found to be the cause of considerable expense, not only for replacing the brake lining, but also for replacing the brake wheels, drums and shafts which were occasionally broken as a result of trying to make too quick a stop after attaining an unusually high speed. The castings were made heavier, and the new shafts were of nickle-steel, but even these could not make the operation satisfactory.

Regenerative braking was tried, but the speed resulting from this was high, and very careful manipulation of the controller was necessary. Lowering with the motor on the first point in the hoisting direction was naturally found to be extravagant in the use of current and hard on the motors.

It was finally decided to place small motor-generator sets on the bridges, to apply low-voltage direct current to the stator windings and to change the controllers so as to provide for this system of braking. After this new apparatus was installed and adjusted, the results were such an improvement in the control over bucket and trolley that brake trouble became a thing of the past and the output of these bridges reached a point considerably higher than had been expected.

Reports have recently been received from one of the companies operating these bridges that after making careful comparison between the records of their a-c. plants and the later ones built on d-c. docks, that in figuring on new installations they would consider an a-c. plant to be equally as desirable as one operating on direct current.

Opening address delivered at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 17, 1915.

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THE IDEAL ENGINEERING SOCIETY
President's Address

BY P. M. LINCOLN

WE ARE meeting here today for the third consecutive year in a midwinter convention of the American Institute of Electrical Engineers. It is an innovation which, as I have indicated started two years ago and has been so successful in the previous attempts that the indications are it will continue. We trust that this particular midwinter convention will be no exception to the rule of success which has attended the previous meetings.

Perhaps I can do no better in the introductory remarks I am to make than to indicate my conception of some of the functions of the ideal engineering society. To go back to first principles, I conceive that the simplest form of an engineering, society—the original model, if you please—is found in the engineering college student who has encountered some question or problem—be it calculus, mechanics, descriptive geometry, or what not—which he finds himself unable to understand thoroughly. He takes that problem to his professor or instructor, or possibly to a fellow-student, and asks for assistance or enlightenment. The meeting of those two minds in the request for, and the giving of information, constitutes an engineering society in its simplest form. This quest for information on the one hand and ability to give it on the other, constitute the fundamental basis of this as well as every other engineering society. We have increased in numbers, to be sure—we are nearly eight thousand strong—and we have limited the scope. This Institute deals only with problems electrical; but we have not altered to the slightest degree the fundamental reason behind the meeting of those two minds; the one in quest of information, and the other with the ability, or at least the willingness, to give that information.

There is one other change that has come with age and numbers. The quest for information always has been and always will be with us, but unfortunately the ability to give it is not.

The meeting of minds has become not like that of student and teacher, where one mind is much better equipped than the other, but has become one where the mental equipment is much more nearly equalized. We are all seekers after knowledge that oft-times none of us have the ability to give. But we do not stop the search on that account. Knowledge grows in the exchange of ideas.

That term "exchange of ideas" is one that has always had a peculiar fascination for me. Knowledge increases with the exchange of ideas. Did it ever occur to you that the value of an idea, no matter how important that idea is in itself, is absolutely nil until it is communicated to some one else? The value of an idea is not enhanced, but destroyed by hoarding. Of what use would Sir Isaac Newton's ideas on gravitation have been had he not set them down in his Principia? Of what use would be the genius of a Steinmetz did he not present papers before the American Institute of Electrical Engineers? No; ideas grow by exchanging and die by hoarding. It is in this exchange of ideas that our Institute finds its highest usefulness. I conceive that an "idea exchange," as exemplified in our Institute is of infinitely more value to the human race than a "stock exchange." Every time a share of stock is exchanged, it pays the toll of the broker's commission and its value is decreased just that much; not so, when an idea is exchanged. With every exchange of an idea it is exhanced in value. Thus, the "capital stock" of ideas is constantly growing. Our Institute is a force in that growth, and it is a force that is worthy of our best effort. Let us continue that effort by bringing here our best ideas for exchange.

Introductory address delivered at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915.

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ELECTRICAL PRECIPITATION

Historical Sketch

BY F. G. COTTRELL

MY FUNCTION this morning, I feel, is more that of an enunciator than anything else. What you really want to see, I know, is the experimental side of this matter and the pictures, both in motion and in still life, that the other speakers have to show you. All I shall try to do is to outline briefly a few of the steps that have led up to this work and give it a little better setting in time and space.

If we go back to the earliest reference we can find on the subject of the application of electrical forces to precipitation, we find, as far as I know, that Hohlfeld, in 1824, was the first to point definitely to the phenomena as a practical matter. Hohlfeld was a teacher of mathematics in the Thomas School of Leipzig, and published a brief article on this subject, which is filed in Kastner's archives in Nuremberg, Vol. 2, page 205-6, 1824. I had rather hoped perhaps we could show this morning an exact duplicate of this described experiment, but it was not convenient or possible to get a static machine here in time for the work. What he did was simply to take a piece of paper, form a funnel out of it, settling the lower tip into a bottle, and lighting the edge of the paper until the smoke filled the bottle, and then placing a wire through the stopper of the bottle, within about three inches of the bottom, and connecting to it an old fashioned friction machine which separated the smoke in the bottom of the flask or bottle. One of the experiments which Mr. Bradley is to show you later is substantially a duplicate of that experiment of Hohlfeld's. It is perhaps worth while to note the words in which Hohlfeld expressed his ideas on this subject: "It is, of course, well known that during a thunder storm, after almost every bolt of lightning, there comes a heavier fall of rain, and this occurs, indeed, just such a period after the bolt as would be required for the water to reach the earth from the clouds. It has also been observed that following a thunderclap, and especially the heavier ones, sleet and hail often fall and in increasing amounts with repetition of the discharges. Finally, it has been noted that so-called cloudbursts are usually preceded by strong and rapidly repeated discharges. The first of these phenomena may easily be illustrated with the use of artificial electricity." Then he describes the experiment of which I have spoken. That constitutes our first historical reference to this subject, so far as known.

This fell, apparently, on deaf ears; no one appreciated its importance. The machinery available was, of course, inadequate for commercial work, and nothing again appears until 1850, when C. F. Guitard mentioned a similar phenomenon which he independently observed on tobacco smoke in a bottle in much the same way. His article appears in the Mechanics Magazine of London for 1850, a quarter of a century after Hohlfeld published his article. Then, the matter seems to have rested without further notice, with an occasional incidental reference. Foı example, there was a reference in 1878 in Vuo Am. by Robert Norwald, on the dispensing of dust inside an electrometer he was working on, showing that the conductors of the air disappeared when the charge was left on, and he ascribed it to this cleaning effect of the air. That is merely incidental, and not anything that was put into practical effect.

The first attempt actually to apply this principle in practise, in technical methods, seems to have come almost simultaneously in Germany and in England. We find a record of a patent issued in England to A. O. Walker, the superintendent or manager of one of the large lead works in England, who obtained a patent dated August 9, 1884. We also find a record of a German patent issued to Dr. Karl Moeller, this patent being dated October 2, 1884, the same year, and only a few months later. Both of these seem to be entirely independent of the earlier work, and seem to be again practically rediscoveries of the fact. All we can learn about Walker's process is through the outgrowth of some experiments and observations made by Oliver Lodge about that time, although Lodge's only publication of the fact was somewhat later than the date of this patent, evidently indicating they had been working together on it, probably before Lodge's publication took place. Lodge's own publication of the facts in a scientific form in the journals is comprised in his paper read before the Royal Institution, in May, 1886, nearly two years after Walker's patent;

and later in the same year, 1886, in November, he read a paper before the Society of Chemical Industry, in which he considerably elaborated on the phenomenon as applied to practical purposes. It is interesting to note in the paper presented by Lodge to the Royal Institute, that what he was after in that case was primarily, not electrical precipitation, which came as an accident of an independent investigation, but he was studying the effect of hot and cold bodies on dusty matter. It had been known for a long time that if you took a hot iron rod and held it in a cloud of smoke or dust and looked along the edge ot the rod you could see dark spaces between the rod and surrounding cloud of smoke and dust, and considerable work had been done by various investigators to explain the theory of this dust or cloud. It was assumed to be the combustion of the particles surrounding the rod. It was afterwards shown that this would occur with a rod not only hotter than the space surrounding it, but colder than the space, and so finally it was run down to a question of molecular bombardment. Lodge employed that and tried to determine whether any electrical phenomenon were associated with this purely thermal phenomenon, and he connected them up to voltages of 100 and more, and found no effect, but when he went to thousands of volts he was surprised to find that a manifest activity was produced, that the smoke or dust was driven away from the rod, and rapidly deposited, and it was at that time his attention was first called to the phenomenon independently of his earlier work. It was only years atter that he came across these references, and he published a brief historical note citing them and giving credit to the investigators for their work, although they were unknown to him at the time of his discoveries.

These two papers which Lodge prepared and delivered at these two institutions, the Royal Institution and the Society of Chemical Industry, served to bring the subject clearly before the public, and I think it is fair to say that the place of precipitation in our modern lines of thought dates from that time. The work of Moeller, while following somewhat the same line, did not appear to produce the same effect on the public, because it only appeared at that time as a patent, and was not followed by any further general publicity, and disappeared from public attention.

While we find Lodge's work referred to in various journals from that time down to comparatively recent years, and a number of patents covering details of proposed methods occurring here and there in the literature, there was nothing that could fairly be considered as a permanent contribution to the technical developments of the subject until quite recently.

Just following Lodge's original patent, there was an installation put in at the works of Mr. Walker—whose name appears as the patentee—at the Dee Bank Lead Works in England, which consisted of two Wimshurst machines. The Wimshurst machine had just come out at that time, and the descriptions of this plant seem rather amusing today on account of the terms in which they describe the Wimshurst machine. It was so vastly superior to the friction machines in use before that time that they considered it a commercial piece of apparatus, a thing which would revolutionize the industry, and static electricity would come into practical use, which we know has not been the case in any such measure as was anticipated.

Current from these two large Wimshurst machines, which were six feet in diameter and were driven by a small steam engine, was carried to the flues of the lead smelter and pointed rods were placed in the flues, with barbed ends distributed over them, and the discharge from the machines was distributed to the gases from these discharge terminals, the other terminal of the machine being grounded. The descriptions we have are simply of the installation while under construction, and after that we hear nothing about it, so it evidently proved impracticable to maintain in continuous operation and disappeared entirely from the technique.

About 1905 some of us happened to be interested in these same problems, the clearing of fumes from acid works in California, and experiments were undertaken by the University of California to determine the practicability of these general methods, using more modern apparatus, or substituting the modern high-tension transformer with the auxiliary apparatus necessary, for the friction machine, and working out a more efficient system of electric distribution.

Out of that grew some interesting laboratory experiments which looked promising, and these attracted the attention of some of the local manufacturing concerns who were willing to carry the work further. It was very soon found that the work would have to be put on a more stable basis than it was possible for us to do as we were working, several of us at the University, members of the staff, and carrying the thing to a practical issue.

That led eventually, to the organization of the present institution which is handling the work. It was realized that it would be difficult for the University itself to undertake this work, and there was a distinct prejudice against purely commercializing the matter in the hands of any one commercial organization. A scheme was worked out to develop the patents under the guidance and backing of local capital, with the understanding that when the money invested had been returned, and a reasonable profit secured, that then the patents, as a whole, should go over to some holding organization to be used for the benefit of scientific research. It was expected then that would be the University of California, because all of us who were working on the problem at that time were alumni of that institution. As the work developed it took more time and money than was anticipated, and by the time it had become stabilized, which was a matter of five years, the work had spread over such a large territory that it seemed impracticable to attempt to administer it from a single institution, and we foresaw the danger, if it became successful and was handled from one institution, that the same sort of procedure would naturally be emulated elsewhere, and before we knew it the very thing which we wanted to prevent, that is the commercializing of educational laboratories, would be really brought about by the fact that we would be competing among one another on a commercial basis, and that would be the most dangerous effect we could bring about. To obviate that, we looked for a solution in finding some national, or better, international, body, to undertake the administration of these rights, and any others that might come in the same way, which would include all research work of this character; an organization in which all the different academic activities, universities and colleges could co-operate.

To make a long story short, after considerable search for the best means of carrying this out, the patents were turned over to the Smithsonian Institution, and by it transferred to a corporation which was formed under its auspices—its guidance at least—called the Research Corporation, organized as a business organization with directors and a charter, to conduct the business of the research work, and to turn over the property to the Smithsonian Institution and other national institutions, and it is under the guidance of that organization, the Research Corporation, with which probably many of you are familiar, that the work which immediately grew out of our activities in California has developed.

Right alongside of that came also a similar development here in the East. About the time I was starting out on the final consolidation of this work under the Smithsonian and the Research Corporation, in the East Prof. Robert Kennedy Duncan was busy with his plan. I presume most of you are familiar with the fact that they have a system of Industrial Fellowships at the University of Kansas and University of Pittsburgh, and one of the problems he undertook as a part of this general program was the same problem of smoke and dust elimination. We worked in the West particularly on smelter smoke, and in the East he worked on black smoke, and his specific problem was the City of Pittsburgh. In this particular field, he was supported and financed by Mr. R. B. Mellon, of Pittsburgh, and out of this work, together with the other work on fellowships which was in his hands at that time, finally grew the Mellon Institute of Industrial Research, and School of Specific Industries, located in Pittsburgh, and the beautiful new building, which is to be dedicated this coming week, stands as a splendid monument to Dr. Duncan's energy and devotion to that work. He was, as you know, most unfortunately taken from us last year by death, at the time when he was just getting into his full energy and usefulness in this work, but, as he told me shortly before his death, he felt that the work had come to such a point that it would stand. He said, "I have been nervous about this whole matter, for fear I could not carry it far enough to have it thoroughly stabilized when I might be taken. I have carried it now to such a point in the last few months that that fear is eliminated, and I have it now in hands I am confident of," speaking particularly of his associate, who has since succeeded him, Dr. Raymond F. Bacon.

The work of the Mellon Institute in smoke abatement was wider than our work; it covered not only electrical precipitation, but other fields; electrical precipitation was, however, a prominent part of it, and from the first, even before the details of his plan were taken up, Dr. Duncan and I discussed the work and arranged a tentative plan of co-operation. At that time both the work of the Research Corporation and the work under his direction was still in such a formative period, that it did not seem wise to try to make a formal arrangement or cooperative plan between them, but to work it out as we went along, and see how the work came out, and it was agreed we should do it in that way until such time as the work was sufficiently stabilized to bring them together.

That has pretty well transpired, and the two institutions are now working together to a common patent situation, the patents developed by each are being now, to a very considerable extent, consolidated and operated in a co-operative manner. The Mellon Institute is working for the same general aims as the Research Corporation, the methods of its administration varying somewhat from those which we have adopted in the organization, but they are each mutually supporting the other. The field of the Mellon Institute in the precipitation work will be more particularly in the immediate vicinity of Pittsburgh, for the immediate future, at least, and the Research Corporation working co-operatively with them, but also over the rest of the country, where work is already started.

These details will be understood better from the papers to be presented. Prof. Nesbit and Dr. Strong will speak for the work of the Mellon Institute, and Mr. Bradley will speak for the work of the Research Corporation this morning, and they will give you an idea of the relationship of these organizations. It has been a great satisfaction to me to see this come about, because I knew Dr. Duncan and valued his friendship very highly, and we both had this same view in mind, of thorough co-operation between the two organizations. I know there is nothing that would please him more than a knowledge of the results as they are now working out, and I feel sure the same applies to Mr. Mellon, who has so generously endowed the work of that Institute. So much for retrospect.

As regards the actual work, the apparatus will tell the story better than I can. I will not attempt to speak on that side of the work. I might say just one or two words in regard to the future, and some of the things we hope to see worked out, and perhaps one of the most interesting of these comes up in the form of the question—How far can this work go beyond what has actually been done and will be brought to your attention this morning in the papers? In Lodge's original plans there were two distinctly separate conceptions, two separate lines of attack, one was directed at the precipitation or collection of industrial fumes and smoke, house smoke and volatile matter, or at least man-made fumes. The other was directed to the question of fog precipitation in the open, the clearing of routes for navigation, the clearing up, particularly, (as the idea existed in Lodge's mind) of the fogs of London. That in one sense looks like a greater task, like a more hopeless task, than those we have undertaken. In another sense, perhaps it is in some ways the easier of the two. It is a field we have kept thinking of, up to the present, feeling that we had our hands full enough with direct commercial developments of fume precipitation. The latter were matters in connection with which we could get direct financial support from individual firms, and the clearing of fog in the open is a thing which it will be harder to interest business interests in. It is a matter of public interest, and we felt that we could best attack that after the other work had been established. Also it is a matter which will require probably more powerful apparatus, and the small installations that have grown up to the present time have been a forerunner of that. Having developed the apparatus up to the point where we are now, it is time to make a start on the other work.

Another reason I personally had in rather discouraging an attempt to undertake that work in the earlier history, was that I thought that was particularly a problem of Sir Oliver Lodge's, and I had hoped that our work would reach a sufficient basis in practical success so that by the time that came to be taken up we could make a real effort to have Sir Oliver associated directly with the work in a way that would illustrate and emphasize the credit that is due him as the father of this whole art. I thought I saw an opportunity for that in the coming of the International Exposition at San Francisco, and particularly in the International Electrical Congress which was planned, and efforts were made to get such a program under way to carry out some of these experiments in their application to fog work at that time. These plans were thoroughly well under way, when the outbreak of the war, as you know, made the holding of the International Electrical Congress impracticable, and then the matter came back for consideration as to whether it was worth while to carry it out anyway. In the meantime, it was found that the amount of apparatus which would be necessary had been pledged, and that there would be facilities for handling extremely high-tension, high powered apparatus at the exposition. There will be a good deal of it there and available for such experiments, and the local electrical departments of the two Universities have taken an active part in that and preparations are being made to do what can be done at the time of the Exposition to carry on some of these experiments.

While I have been here in the East on my present trip, I have been very much pleased to find the interest which is being taken in this matter. The possibilities of such experiments are growing right along among the shipping and other interests, to whom the fog question is a vital one, and I think it is entirely probable that within the next few months a direct start may be made in experiments along this line. Lodge has carried out some very startling experiments in this direction already. On the top of the building in his old headquarters at the Physics Laboratory at Liverpool, before he left there to go to Birmingham, he erected a mast, practically a flagpole, carried a wire up that to the top, and charged that simply from a series of large electrostatic machines available at the laboratory, and was able to gradually dissipate the fog for several hundred feet around the wire. This, at least, represents what may be hoped for. My own feeling is that the line of attack we will take up here, not to mislead you in what I have said, would be somewhat different from that. I think with the development we already have in precipitation, that the method would probably lie more in finding a means of carrying an electrode system, slightly modified, but in general not so different from those at present in use in the flue systems, in front of the vessel that was to be protected from fog dangers. Aerial problems are coming fairly and distinctly in the field of the engineer, and in talking with aeronautic people they do not see why there should be any question of carrying at a couple of boat lengths ahead of the vessel, from each side, an apparatus such as the electrode system, and by connecting that to high-tension apparatus, such as you will see operating here, on shipboard through the cable that is supporting this motor, you would have a broom, so to speak, sweeping a path clear in front of that vessel, that would give you room enough to stop if you were about to run into anything. If you wreck the heilocopter, that does not amount to much, and that can be deflected in a shorter time than that in which you can stop a large vessel. I do not put this forward as a definite program or finished piece of work. It is offered purely as a suggestion as to the line of work that may be taken up, but I wish to say it is not half as big a jump into the dark as it would, perhaps, seem at first sight. Some of the steamship people in New York have indicated their willingness to go forward with the work and supply the necessary means to carry on preliminary tests to see what may be done in the matter, and it is hoped some such development may take place in the near future; and I bespeak your cordial help and co-operation as members of the electrical profession in helping this good work along, because it certainly should add very materially to the safety and comfort of people traveling at sea, as well as materially assist in solving many problems on land.

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SYMPOSIUM ON "THE STATUS OF THE ENGINEER"

ADDRESS OF L. B. STILLWELL

IN ARRANGING the program for this evening the committee to whose efforts the presence of our distinguished guests is due gave consideration to the question whether it would be wise to attempt to suggest to the several speakers various more or less definite aspects or phases of our broad subject, with a view to avoiding repetition of thought and securing a comprehensive and systematic discussion. It was felt, however, that the most useful and constructive results might be expected if the gentlemen who are to follow me were simply invited to present for your attention those views and suggestions—based not only upon their exceptional experience as leaders in various departments of engineering accomplishment, but also upon their wide observation and experience as men of the world—which to them, severally, may appear of special interest and importance to the profession. If repetition results, emphasis will result, and the status of the engineer, as a professional man and as a citizen, can be systematically advanced only by that individual and that collective effort which it may be hoped will result from that conviction which follows the emphatic statement and reiteration of essential facts.

At the outstart, the expression "Status of the Engineer" appears to require definition. It may be interpreted to mean the standing of the engineer as it appears to his fellow citizens, or it may mean his standing as it would appear to an observer seeing facts as they are, without exaggeration, without diminution and without distortion. It is the well-known distinction between reputation and character. Reputation is the image of the man as he appears to those about him; character is the man himself. Not infrequently does it happen that the image bears little resemblance to the actual man. When this occurs the fault is sometimes that of the observer, but not less frequently, perhaps, it is the fault of the man himself.

Tonight, I take it, we are concerned with both aspects of our subject. What we may be able to do to make ourselves more competent as engineers, more useful as citizens, or better as men, is obviously of importance to every member of the engineering profession. What we may be able to do, by individual and by collective effort, to secure for the members of our profession that recognition by the public at large to which their character as men, their professional ability and their work as contributors to civilization and progress may justly entitle them, is also of obvious importance. Each of these broad aspects of the subject affords inviting opportunity for analysis and for useful suggestion along various lines of thought; but in introducing the discussion I shall make no attempt to treat the subject comprehensively, but shall endeavor to utilize the time which has been placed at my disposal by inviting your attention to certain opinions which I have formed, as the result of observation and experience, and submitting certain suggestions in regard especially to collective, or at least co-ordinated, policy and action by our great national engineering societies which in my judgment would tend from every point of view to improve the status of the engineer.

The opinion is widely prevalent throughout the ranks of the profession that the true status of the engineer is not recognized by those about him; that the work which he has done and is doing in the world entitles him to a larger place in the public view than he now occupies and to a larger share in the administrative work of the nation, state, local community, and of our great railway and industrial corporations than he now enjoys. Dealing with facts, as his scientific education and professional training have taught him to deal; trained in the solution of economic problems to exclude all that is irrelevant or immaterial and to deduce his conclusion by a process of exact reasoning from ascertained premises, he is amazed to observe a great economic question like, for example, the conservation of our water powers, involved in a fog of misunderstanding and misrepresentation so dense that neither the public nor our lawmaking authorities can be expected to see it in its true proportions. Knowing, as he does, that no education leads with greater certainty than that of the scientist and the engineer to the formation of sound opinions and well-grounded, conservative judgment, and believing, as he does, that the ranks of no other profession include a larger proportion of men of clear view, broad intellectual comprehension, unblemished character and executive force than are found among the members of our national engineering societies, he finds it difficult to understand why the appointment of an engineer as a member of one of the many commissions of investigation and of administration, to which in these days the functions of government in this country are increasingly confided, is a phenomenon of extremely rare occurrence. His conclusion generally is that these are matters for the politician, not for the man trained to view facts in their true light, unwilling to misrepresent or mislead the public for political effect or to seek preferment by following the usual well-worn paths; and too often he follows up this conclusion by burying himself in his scientific studies or professional activities. Such a decision can be in no way justified. As a citizen trained to see true, to think straight, possessed of special knowledge regarding many of the great economic problems of our time and conscious of ability to deal with them effectively, it is the duty of the engineer to assert himself as a citizen. Recognition in time will overtake and keep pace with achievement if we do our part, not only as men of specialized training, but also as men of the world and as citizens who, by reason of that very specialized training and experience, owe in a peculiar sense a duty to the community, in these days of vast and complex economic and social problems, which in themselves are a result of the work of the applied scientist within comparatively recent years. The engineer who buries himself in the technique of his profession cannot justly complain if he fails to attain a position as a leader of men. Like Franklin, he must at times leave the laboratory of science for the forum of discussion and the hall of legislation, if he would fulfill his duty as a citizen and secure that recognition of his intrinsic ability which he desires and to which he is entitled.

In his scholarly address delivered at Ottawa on June 18, 1913, Dr. George F. Swain, President of the American Society of Civil Engineers, brought to the attention of the oldest of our national engineering societies many facts which are of profound interest to all professional engineers. His discussion is philosophical in thought, felicitous in expression and singularly convincing in its reasoning. It should be read and then read again by every man who is, or aspires to be, an engineer. His subject was: "Some Tendencies and Problems of the Present Day and the Relation of the Engineer Thereto." Neither the present status of the engineer nor the responsibilities which in a peculiar sense devolve upon him in these days of vastly accelerated economic progress can be realized clearly without an examination of these tendencies and problems. It would be difficult, if not impossible, for any man to improve the admirable discussion of the subject which Dr. Swain has given to the profession in the paper referred to, and I earnestly hope that every engineer present this evening will secure a copy, will read it carefully and thoughtfully, and then will do what he can to oppose and correct the unfavorable phenomena of our time to which Dr. Swain calls our attention. The time at my disposal does not permit even a résumé of these phenomena, and I pass, therefore, to the question, " How may the status of the engineer be improved?" However we may differ in our views of what his present status is, we are unanimous in the desire to see that status advanced. The practical question which interests us is, what can we do to secure this advancement; what can we do, by individual and by collective effort, to make the engineer still more effective in his professional work and more useful as a citizen, and to secure for him more general and more definite recognition by the community at large?

Obviously, there are several lines along which intelligent and systematic work may be expected to promote the attainment of these objects. While recognition may lag behind achievement, we may nevertheless rest assured that every advance in the character of the engineer and in his ability to perform his work effectively will be followed by increased recognition of his position as a man and as a professional worker in the community. In this connection, next to integrity of character, education is of fundamental importance. In our schools and colleges the aim should be to train the mind rather than to impart technical information. The curricula of our technical schools differ so widely that safe generalization is difficult, but in my opinion the tendency should be toward a decrease in the time allotted to technology and an increase in that allotted to certain of those subjects which comprehensively are grouped under the name " humanities." It is greatly to be hoped that the time may come when no American institution of learning will confer an engineering degree except upon a student who has completed a four-year course in arts or philosophy and a two-year course of technical instruction in the department which he may select. It is not essential perhaps that the engineer should have studied Greek, but in my opinion no degree in engineering should be granted to a man who has not studied, for example, logic, rhetoric and political economy, as well as mathematics and the essential branches of pure and applied science which in his education have particular reference to his specialty.

Moreover, a man's education is not completed when he receives his degree at graduation. It would be as true, perhaps, to say that it begins at that time; and, without attempting to discuss the subject at length, I may be permitted to suggest that the average engineer, ten years or twenty years or thirty years after graduation, will be not only more interesting to himself and to his friends, but will be also a more effective engineer, if he has not confined his attention exclusively to his special line of practise but has availed himself of the many opportunities which occur in life to broaden his horizon and to add to his store of knowledge in departments of intellectual activity other than that which he has made peculiarly his own.

Primarily each engineer must make of himself what his ability and opportunities may permit. This, and this alone, can fix his professional character—his true status. But, while character is far more important than reputation, reputation also has its value, and a correct appraisal of the engineer by the community at large is to be desired, not only because of its effect upon the engineer himself, but also, and more especially, because of the vastly increased utilization of the engineer's abilities in the service of the community which would result.

It requires no argument to show that the community at large cannot be expected to appraise correctly the capabilities of the engineer if the latter adopts and systematically pursues throughout his career a policy of total abstinence from every form of indulgence in public affairs. I have already touched upon this point briefly, and I trust that it will be developed and emphasized by other speakers this evening, some of whom, by example as well as by precept, have illustrated and taught this doctrine in a manner which already has done much to demonstrate to the American public the fact that the same kind of brains which the investor selects to solve a complex problem of engineering construction, or to find gold where others cannot see it, can be relied upon to find the answer to a complex economic problem requiring legislation, or to point out an essential principle which has been concealed by a mass of irrelevant rubbish.

Our national engineering societies can do much to secure for the engineering profession the recognition to which the character and the achievements of its members justly entitle it. For years they have been doing splendid work in the post-graduate education and training of their members, by affording opportunity for the presentation, discussion and dissemination of technical information, but as yet have they failed to establish for the profession a standing in public estimation comparable, for example, to that of the legal profession.

Let us consider briefly certain measures, apparently within the power of our engineering societies to adopt and enforce, which if adopted would tend to correct this situation.

Our engineering societies can do much by the exercise of unceasing vigilance in preventing the admission to our ranks of unworthy or unqualified applicants. In the absence of any system of federal or state license under which the professional engineer may qualify and practise, even that part of the public which may attempt to exercise intelligent discrimination can base its opinion of the qualification or lack of qualification of the engineer only upon the fact of membership or non-membership in one or more of the great national engineering societies. And what have these national engineering societies done to define and establish the professional standing of their respective members? Without undertaking to answer this question specifically, it is probably fair to say that, as regards at least two of these societies, the requirements for admission and the scrutiny and selection of new members are all that can be expected and possibly that could be desired. Some of the societies, however, apparently might "stiffen" their requirements for admission, to the advantage of the entire profession, and might draw more distinctly perhaps the lines which segregate the members into several classes or grades which are supposed to correspond with more or less accuracy to the comparative professional qualifications of those who compose them. Nevertheless, it is a fact, I believe, that membership in a national engineering society today means more than it did twenty years ago and that the state, municipality, corporation or individual seeking to employ an engineer is less likely now than then to select one who has not been recognized by his professional brethren as worthy of membership. But, aside from the advantage which would result from bringing the requirements for membership in all of these societies up to the level of those which have adopted the most advanced standards, there are several important steps which the national societies might take which undoubtedly would contribute materially to the advancement of the status of the profession.

(1) Several of our national societies have adopted so-called "codes of ethics" or rules of practise. Many of these rules involve no questions of ethics. They are rules deemed by the respective societies useful to their members in their professional practice, and their enforcement or non-enforcement has no particular bearing upon the status of the engineering profession as viewed by the public.

In so far as ethical principles are involved, however, whether a code be adopted or not, there can be no question that the adoption and enforcement of rules which would result in the prompt expulsion of any member proved guilty of dishonest practise would do much to increase general respect for the profession. Up to the present time our societies have signally failed to establish their position in public confidences by disciplining members even in flagrant cases. At a comparatively recent meeting of the American Institute of Consulting Engineers, a distinguished member of that organization and of the American Society of Civil Engineers made the statement that an examination of the records of three of the great national engineering societies failed to disclose a single instance in which a member had been expelled for violation of the ethics of the profession. Even in certain cases where a member of the society has been convicted by the courts, the society has failed to expel and has allowed the member to resign. I am aware of the responsibility which a society may assume in branding a member by expelling him, but until the societies have the wisdom to so amend their rules as to provide for expulsion in flagrant cases and the courage to expel, they cannot expect the public to accept the fact of membership as in any sense a guarantee of professional honor. Surely the establishment and enforcement of regulations which would result in the prompt expulsion of a dishonest member is a step which each of our engineering societies can take. To the great credit of the profession, it may safely be said that the number of instances in which such action might be justified and necessary would not be great. The effect of a few salutary punishments of this kind would be far reaching and might be confidently expected to improve the standing of the society in the eyes of the public. Our friends the lawyers have long recognized the necessity of fortifying the status of their profession by providing, through the medium of their bar associations, for the trial and expulsion of members who may violate the ethics of their profession. How strictly this rule is enforced I cannot say, but it is evident that even the occasional enforcement of the rule must contribute effectively to the establishment of the public standing of the profession.

In my opinion, no society by a single act could do more to advance the status of the engineering profession than could be accomplished by conspicuously expelling any member found guilty of dishonesty in the practise of his profession.

(2) Perhaps the most encouraging evidence that our national engineering societies are coming to recognize the fact that co-operation in matters of common interest is essential to the well-being of the profession, is to be found in the action recently taken by six of these societies, through the appointment of a joint committee which has agreed upon a bill for licensing engineers which has been submitted to the governing bodies of the several societies. It is earnestly to be hoped that the governing bodies of these societies will lose no time in bringing their best judgment to bear upon this extremely important question and, having reached a decision, will take effective action to safeguard and promote the best interests of the profession.

(3) The national engineering societies can advance the status of the profession by exerting themselves to direct public policy in economic questions along sound lines of development. I have not informed myself recently in regard to the policy and action of other societies, but for several years past the American Institute of Electrical Engineers, from time to time, has sent committees of specially qualified experts appointed from its membership to appear before various heads of departments at Washington, or before committees of Congress, in relation to such questions of fundamental economic importance to the country as, for example, the utilization of water powers on the public domain and in navigable streams. These committees have discussed only the engineering and economic aspects of the questions under consideration. They have been careful to avoid all political or legal questions. Their reception in every instance thus far has been not only respectful but courteous, and it is believed that the information which they have been able to convey has been useful to the authorities. The members of the several committees have paid their own expenses. They have rendered this service because they have realized that legislation

permitting, for example, the control and development of water powers upon sound economic lines is of very great importance, not only to those members of the engineering profession whose activities are concerned with hydraulic or hydroelectric development, but to the country, at large. Along such lines as these, there is no valid reason, in my opinion, why all of our great national engineering societies should not co-operate in placing at the disposal of our national legislative and executive authorities, from time to time, the special knowledge which is possessed by their representative members and which the authorities must have if mistakes that may result in great harm to the economic interests of the country are to be avoided.

ADDRESS OF E. W. RICE, JR.

THE SUBJECT for discussion this evening is important and timely, and should be of vital interest to every engineer. It is well for us to pause a few moments from our daily task and make a brief survey of the engineer's work, to consider its important influence upon the life of this busy world, and especially to enquire what new service awaits the engineer now and in the immediate future.

During this discussion we do not propose to limit our definition of "engineer" to one educated in or following the strictly technical profession of civil, mechanical and electrical engineering, but shall include in addition all educated men laboring in the broad fields of chemistry, physics, medicine and other organized scientific activities.

I do not think that we can be accused of serious exaggeration in saying that the world is indebted to such men for the application of steam to ships, cars and workshops; for the invention of the sewing machine, the typewriter and the phonograph; for the introduction of the bicycle, automobile and aeroplane; they have brought the marvels of photography into existence, giving us the moving picture, X-rays and colored photographs. High explosives have been created to build and to destroy. We must thank such men for the untold blessings of anesthetics; for showing us how to successfully limit and combat epidemics of dread diseases.

Coming to our own special field, the members of our profession have given the world the telegraph, the ocean cable, the telephone and the wireless; created electric lights for our homes, cities and workshops; the electric motor to run our trolley cars, railroads and factories; have designed dynamos and great transmission lines with which to save and make useful the otherwise wasted power of our waterfalls. These and many other contributions equally wonderful and equally useful—miracles at first but now mere commonplaces and necessities—have been evolved from the brains of our busy scientific engineers largely during the past 40 years.

But I will not weary you with a further recital of engineering achievements, as such a recitation of even the shortest possible catalog would consume the entire evening.

My object in thus calling attention to the relatively recent contributions of engineers to the wealth and resources of the world is not to tickle your pride in belonging to the engineering profession, but rather to awaken your sense of responsibility for the great changes in our daily life, our methods and opportunities of conducting business and all other activities, which have been brought about directly and indirectly by such accomplishments, and to make some suggestion for the meeting of this responsibility.

Is it not a fact that civilization in its present form would never have arisen and would speedily come to an end if deprived of the engineer and his services? Has not the equilibrium of the world been upset by these very gifts of the engineer?

Is it not evident that such tremendous additions to our power, knowledge and wealth must have a powerful influence upon every phase of our existence? Have not our relations with nature and with each other been profoundly affected, and as a result required many new adjustments?

The discovery of new trade routes has, as well known, completely changed in times past the history of nations and the fate of their peoples. The discoveries of our scientific engineers during the past 40 years have been of greater importance than discoveries in trade routes, and it is inevitable that in adapting itself to the new conditions society should be deeply affected. The adaptation of man to his new environment could not take place without strain and friction. Are we not now in the midst of such a process of adjustment?

Of course, we all appreciate that the labor and thought of many other men of vision and enthusiasm were needed; men experienced in finance, commerce, trade and government, to render the all-essential aid required to introduce and to adapt to our daily lives these great contributions. But it would seem to be self-evident that without the creative work of the scientific and technical engineers these things would not have seen the light of day.

This remarkable development was fairly started during the first half of the 19th century under the guidance of the civil, mechanical and chemical engineer, but was tremendously accelerated by the advent of the electrical engineer about 40 years ago. His work during the past decades has reacted upon that of the other engineering professions and stimulated and made possible the almost equally marvelous development in mechanical, chemical and other lines of activity. Therefore, I regard all those who have been able to participate in the service of electrical science as happy and fortunate individuals. It is true that financial reward has not always been great; on the contrary, it has often been extremely meager when compared with the rewards which frequently come to the successful lawyer, financier or merchant, but our engineer has been rewarded by something more valuable and precious than gold,—the thrilling joy of achievement. There can be no greater satisfaction than that which comes to a man who believes that he is the first to discover some new force or to make some new and useful invention.

I have lived with and worked alongside of engineers more than 30 years. I think I understand the engineer's aspirations and character. I can say that it is a case where familiarity has not bred contempt, but, on the contrary, has inspired respect and affection.

The engineer is popularly supposed to lack certain qualities needed in a successful man of business, or to make a good salesman, or to handle important financial matters, or to fill positions requiring general executive ability. Is this popular idea justified? We may admit that an engineer who has devoted his entire time to his exacting work may be lacking in the knowledge and experience of other lines of activity, but it does not prevent him from having certain natural qualities, integrity, tact and aggressiveness combined with general intelligence and common sense. These qualities are personal and not professional. No group of men has a monopoly of such qualities and in none are they entirely lacking. These qualities are to be found as generally among engineers as among other men.

It has been further charged that as an engineer deals with nature and natural laws his experience has been limited to impersonal objects, and that he must fail to appreciate or understand the complicated human element which is the important factor in business or in political life. This may be also partially true, particularly in the case of some of those whose work has been confined to that of pure research or pure science, but is not a general condition even among such men, and by no means the condition among engineers who of necessity are brought more or less in contact with the human element.

I have noticed that an engineering education and training have generally developed a man's powers of observation and his desire and ability to learn. He becomes skeptical of mere theories, doubts tradition and spurns superstition, but he constantly searches for the truth and is not afraid of facts. He habitually tries to see things as they are and not as he thinks they should be. He is never satisfied that " whatever is is right," but is ever trying for something better. I do not need to tell this audience that engineers do not always agree as to the interpretation of facts, but opinion is frankly based upon facts and not upon preconceived notions. One who refuses to face or acknowledge facts loses his influence upon his fellows and his standing among his brother engineers. The engineer is always " from Missouri."

There is an old proverb which runs somewhat as follows: " One look is worth a thousand words." I like that proverb, and it is, I think, a fair description of an engineer's point of view. How often you hear the expression among engineers—" Well, let's go and take a look at it." Is not this the spirit which is needed in respect to other problems in the social, industrial and political world? Do they not need less talking about and more intelligent looking at?

It is true that the engineer deals primarily with nature, but nature does not lie. The engineer, therefore, learns early in life the utter uselessness and folly of deceit. He knows that it would be silly to the point of insanity to try to fool nature. He is constantly on his guard not to fool himself and is therefore not likely to try to fool others. In fact, he loses in time the desire to deceive, even if he ever had it. Honesty becomes a habit, not the honesty of the old-line trader formulated in the saying, " Let the buyer beware," but the kind of honesty which scorns to take advantage of the negligence or ignorance of his customer, which involves honest thinking as well as honest action. It is quite possible that this habit may make him at first the easy prey of dishonest men, but it is a quality which commands respect and which wins in the end. It is needed and appreciated in business of all kinds and sizes, little and big. It is helpful to little business. But big business is doomed to big and disastrous failure unless saturated with honesty.

The engineer's training also tends to produce in him a fine blend of conservatism and radicalism. He is not afraid of a thing because it is new and he is not slavishly bound to precedent; on the contrary, he is frequently the creator of new things and a breaker of precedent, but he also believes in continuity and is not likely to let go of the old until he has a good hold of the new. He does not adopt an idea merely because of its novelty, but demands before adoption, the acid test that it should be really better than the old.

There is, therefore, a large field of service open to the engineer in manufacturing, commerce, farming and all other business activities of our country for which his education and training have made him eminently fit. In fact, his work in science and engineering, already briefly alluded to, has succeeded in so increasing the magnitude, variety and intricacy of manufacture and trade that the special knowledge of the trained engineer is already in demand in almost all departments of our commercial and business life. Even in the specialized field of selling, the old type of salesman with precious little technical knowledge has been largely displaced by the engineer salesman.

There is, however, another opportunity for service awaiting the engineer of a most valuable and patriotic character. The biggest business, after all, is that of running this great country of ours. The United States not only operates the largest businesses itself in its various departmental activities, but through its legislators and various commissions it has taken a lively and paternal interest in private business. It makes the rules for the conduct of our business which fundamentally affect our future for good or for evil. It seems to me that the engineer ought to take an important part not only in conducting this great enterprise but in helping to make the rules for our faith and conduct.

I recently heard a member of Congress say that in looking in

Congress one was merely seeing as if reflected in a mirror the great people who elected it, and that if we, the people, did not like the looks of ourselves we should not get angry and break the mirror but go and wash our faces. Now, while that was a very humorous and witty simile it seemed also to convey a homely truth and a sensible suggestion. I began to wonder how much there was in the suggestion, and thought I would ascertain just how accurate a reflection of our people and its activities was to be found in Congress and Legislature. I thought it would be interesting to learn the profession or avocation of those whom we have elected to represent us in Congress. I have here a list from which I will briefly abstract:

1914.

SENATE OF U. S.

	Number
Lawyers	71
Farming	5
Banking	4
Publishing	4
Merchants, mfrs., railroads, real estate	7
U. S. Navy	1
Mehical profession	1
Not specified	3
Total	96

HOUSE OF REPRESENTATIVES

	Number
Lawyers	275
Editors and publishers	23
Merchants & manufacturers	32
Other business	32
Farming	14
Banking	4
Educational profession	6
Medical profession	5
Architects	3
Engineers	1
Not specified	40
Total	435

It will be noted that 75 per cent of the Senators are classified as lawyers, and 65 per cent in the House come under the same classification. I may say, incidentally, that I did not find a single one among the senators who professed to be an engineer, and only one in the House of Representatives. An examination of the roster of the State of New York shows a similar condition, a large majority of the membership of both the Senate and Assembly being classified as lawyers. Now, I do not know how these facts impress you, but the witty simile of which I spoke rather lost its point as a conveyer of homely truth in the light of the facts. A body whose composition is about 70 per cent lawyers cannot be considered as a very accurate reflection of the people of this country. Now, I have the utmost respect for members of the legal profession. We are all constantly trusting lawyers with our most important business matters and intimate private affairs. No profession has higher ideals and no profession comes nearer to realizing these ideals in practise. They deserve our confidence. I also yield to no one in my admiration of the ability, integrity and patriotism of the great men whose names have honored the legal profession and shed luster upon our country; men who frequently at great personal sacrifice have given the best part of their lives to the service of their country.

However, I think it is competent for us to enquire as to whether there is not a disproportionate number of members of the legal profession in our law making bodies. Is it for the best interests of this country to have any one kind of talent and training or point of view so overwhelmingly represented? There is a pretty general opinion in this country that we are afflicted with too large a number of laws, and it has been suggested that there may be a connection between the number of laws and the number of lawyers in our legislative bodies. Is it not also a strange anomaly that a country which owes so much of its phenomenal prosperity to the creative work of engineers should have practically excluded such men from its Congress and Legislatures? Would not our general condition have been better if years ago we could have injected into the composition of our law-making bodies a number of high class, sensible engineers? It seems to me that our engineers have a duty to perform, that they owe it to themselves and to the country not to be satisfied with being simply hired to give their views and professional opinion upon programs prepared by other men, but should sit with our rulers and share directly in the responsibilities of government.

It is reasonable to expect that men who have been the greatest factor in the creation and conservation of our material wealth and resources should have sound and constructive ideas of practical value upon the matters which our commissions are created to control. Therefore, our great commissions which are charged with such tremendous power and grave responsibilities should have among their members competent engineers of experience as well as lawyers, practical business men and experts in the special province over which the commission has jurisdiction.

One of the most hopeful signs of the times is the great awakening of the business men of this country to the imperative necessity of taking an intelligent interest in our Government, and it looks as if our business men now propose to make a business of seeing to it that they are properly represented in the business of government. Engineers should arouse themselves and participate in this great movement.

While up to the present no better or more practical means has been discovered than our great political organizations for giving effect to the wishes of our citizens, it is becoming increasingly evident to thinking men that no permanent advance can be made by simply turning out one political party and substituting representatives of another as our rulers. An intelligent and continuous effort should be made to improve the composition of our legislative bodies. We are essentially a nation of manufacturers, traders and farmers. We are all part of an organization with a mechanism which is so delicate, extensive and complicated that it must be controlled and managed with the greatest wisdom and intelligence if we wish to continue to progress in prosperity and lead happy and useful lives. It seems to me that in the future it will be the duty as well as the privilege of the engineer, who so largely contributed to the production of this complicated mechanism, to assist in its management in order to assure its preservation.

ADDRESS OF E. M. HERR

THIS TOPIC is now so wide that there is no difficulty in discussing it from one's own particular point of view and in line with any individual interest and experience. The danger lies in dealing with so broad a subject from too limited and narrow a point of observation. It is doubtless from a full realization of this danger that those responsible for the program tonight have brought men together in this discussion from so many different positions and varied experiences in life.

Having announced my apprehension regarding the narrow view of this broad question, I feel at perfect liberty to proceed to take such view, if only to make good my prediction.

My experience for the past eighteen years has been with the engineer in manufacturing business and the last ten years in a business so highly technical in its character and developing so rapidly, largely through the efforts of these very engineers, whose status we are here to discuss, that it was often a question whether we were engaged in engineering our manufacturing or manufacturing our engineering. As fast as the factory learned how to make a machine or device of any kind, the engineers would bring out an improved design and the shop had to begin all over again and learn anew the lesson which had cost so much in time, effort and material. At such a time one sympathizes with the self-made railroad superintendent of my acquaintance in Chicago, who, after receiving notice from the chief engineer of the railroad that such and such changes must be made or limitations put upon speed of trains or weights of engines, would frequently say: " If we could gather up all the engineers and drop them in the middle of the lake, we could make some money for our stockholders." And so he might have done for a time, but from this remark it is evident this superintendent was desirous of standing still as to progress and improvements. Here we have one answer to the question under discussion, viz.: The engineer stands for progress and improvements. Progress and improvements! What a fine status for any profession. If the engineer always stands for genuine progress and real improvements can much more be desired? Let me therefore counsel our young engineers to adopt this as their slogan, and always be sure, in their engineering reports and recommendations, that they stand for progress and improvements that are both genuine and real.

The engineer is not restricted in his sphere to dealing with inanimate things, broad as is the field of improvement and development of the materials, processes and products of a business.

It was an engineer who first developed the principles of scientific management, and the men who have brought the greatest contributions to the wonderful advance in the handling of workmen, resulting in materially increasing their efficiency without adding to but often lessening the drudgery of their work, have all been engineers.

Engineering, originally the art of managing engines, was later defined as " The art and science by which the mechanical properties of matter are made useful to man in structures and machines." This definition is now far too restrictive and must hereafter include men as well as materials; animate as well as inanimate matter.

In the management of men, the engineer as usually trained, has his severest test. Many engineers, remarkable for their judgment, skill and intelligence, fail dismally in handling men.

The very nature of the training of the engineer tends to unfit him in directing and controlling the rank and file of the workmen. The exact and uncompromising methods so necessary in engineering training cannot be applied in dealing with men. Fairness and justice are the cardinal principles to be used always, but in addition, in dealing with people one must know how to bring the human element into all such relations. When this is properly done, the workman is inspired, stimulated and led into obedience and loyalty to which no severity or rigid rules could drive him.

It might be thought that training and directing workmen is not part of an engineer's work. Formerly this was true, but with the rapid growth in the technical requirements of many kinds of manufacturing, and the development of improved methods of management of shop work, the latter devised and developed by engineers on engineering principles, the old rule of thumb methods of shop management are fast becoming obsolete and either the old men must learn the new methods or our young men with engineering training must learn how to handle men skilfully and fairly.

Another field rapidly opening to trained engineers is the commercial one. The product of many of our factories is so technical, from an engineering standpoint, that only an engineer trained in that specialty can properly present it to prospective customers.

It is, therefore, seen that not only does engineering include, besides the designing and constructing field, the managerial and executive work which also demands this trained intelligence, but even the salesman, who is popularly supposed to be born, not made, is leaning heavily upon the engineering profession. This can only point to one conclusion: In the manufacturing business, the engineer, formerly useful for designs and specifications, is becoming necessary in practically all branches.

The daily increase in the complexity of our civilization inevitably increases our industrial development, and as we have seen, consequently extends and broadens the field of engineering work. Can we wonder then at the enormous increase in the attendance at schools of engineering and the rapid strides made by our engineering departments in the University as compared with those of the academic departments?

It is naturally rather stimulating to our pride as engineers to contemplate the rapidly widening field which the profession is occupying, but we must not forget that with this broader field comes greater responsibility and the necessity for more careful and thorough training than in the older times of simpler conditions.

But, it will be said, while our activities and responsibilities are greater, so also are our resources; and does not the multitude of improved processes, labor saving devices and space and time savers, such as the many kinds of rapid transit, the telephone, telegraph, etc., more than make up for the difference?

In some parts of engineering doubtless this is true, but in what I will call the newest branch, viz., the engineering which deals largely with men and not with machines, the managerial and executive work to which the profession is being called with rapidly increasing urgency, but little help is found in new inventions. In this new field (if such it can be called) the ability to analyze accurately and draw correct conclusions from clearly perceived premises, so essential in general engineering, is just as important.

The difficulty which most engineers find comes from the analysis of cause and effect in the management of and dealing with men and women instead of machines or structures. The former is more difficult as a problem and was formerly only solved by those thought to be specially gifted in their ability to handle men. Like many other so-called "gifts," this one can be learned, not by inflexibility and severity, nor, on the other hand, by weakness and vacillation, but by even-handed justice tempered with humanity.

No fair man wants more than justice and I maintain that very nearly all men are fair or want to be. The difficulty comes in knowing how to deal justly and humanely in every case, and in the pressure and urgency under which business must now be done. He is both patient and wise to a remarkable degree, who can attain unto it.

Is not, however, the man with an engineering training far better equipped for weighing correctly the elements which must enter into such a decision? He is, with but one exception. This exception is his training and tendency to analyze mathematically. The very training in mathematical analysis, so largely a part of an engineer's education, to a considerable extent unfits him for a correct weighing of what I have called the "human element."

As an illustration, there is a great difference in the effect upon an employee of the way an order or decision is given. You all have probably at some time dealt with those in authority, from whom you would rather receive a refusal than an acquiescence from another. An adverse decision would be received from the former superior and carried out with a feeling of loyalty and willingness, but with an unavoidable feeling of grudging obedience and almost revolt from the latter. The different effect upon the employee was caused by the employer's knowledge of and due regard for one phase of the human element in dealing with the employee.

Many other conditions, largely personal in their character, must also be considered and given due weight in an analysis embracing the actions of men and women.

This is the element to which I wish especially to direct the attention of the young men of the profession. That it can be learned, I know from my own experience, which also has taught me its value.

Keep steadily in mind the Golden Rule—Do to others as you would have others do to you—and your judgment, with this in mind, while not susceptible of mathematical proof, will not fail of at least some part of the human element and ring true to the requirements.

Do not misunderstand me to advocate a departure from engineering principles in this matter of dealing with men. On the contrary, they must be dealt with logically and correctly, and a proper application of the principles of good engineering can bring only this result. No correct result can be obtained in any engineering or other problem if any of the elements are left out in its analysis. The human element is a factor and must be included or your result is not true. Therefore, I repeat that the engineer is needed in the shop and other places where men, and women too, must be managed and controlled. In this work his status is broadened and his influence greatly increased, but more important still, the engineer himself is made a more liberal, broader, better and more useful member of society.

Such an engineer will have a broad perspective, because he is accustomed to observe tendencies in both men and affairs and to draw correct conclusions from them. He can lay plans far ahead and, seeing clearly the ultimate result, is able to take full advantage of the tendencies in both his own field and that of allied lines of engineering, not only foreseeing demands but so shaping his activities as to create them.

ADDRESS OF ALEXANDER C. HUMPHREYS

I FIND that I am somewhat at a disadvantage in this symposium, and it is my own fault. I have had the opportunity to prepare an address for the occasion, but I have tried to listen attentively to those who have spoken ahead of me, and I shall try to get my text from what they have said.

I quite agree with the speakers who have preceded me in thinking that there is no reason to dread repetition. There is plenty of room for emphasis in anything we have to say on an engineering subject, or any other subject, for my experience is that in anything we are trying to show to others, or to convince others they should agree with us on certain propositions, we make but little progress anyway. There is a large amount of paraphrasing to be done, and sometimes the discussion and the emphasis lead us to correct our own views.

I think I should first want to lay stress upon the suggestion which has been made by Mr. Stillwell, as to the influence of character. Much is said about the education of the engineer, and especially the education of the engineer in college, yet, after all, the student is not prepared to take his place in the engineering profession unless that question of character assumes its right place. In fact, the more brilliant a man is as an engineer, the worse citizen he may be, if that question of character has not its proper place.

It seems to me that in much of our work in our Institute this question of emphasis might be brought out, because we, I think, bring forth a great mass of undigested material. It is not properly or fully discussed, and the result is our proceedings are filled with undigested material, some of which should be emphatically contradicted. On the other hand, there is much material that should be emphasized and re-emphasized, and therefore I want again to second Mr. Stillwell, this time with regard to that address of Prof. Swain's. I think we could all afford to read that at least once a month, just as I think we could all afford to read Prof. Rankine's dissertation which is a sort of introduction to his Mechanics. I am debating whether I shall not make it a condition of graduation at Stevens that no senior shall graduate unless he can pass an examination on Rankine's dissertation. I wonder how many in this room have read it?

Of course, it would not look well for all of us to get up here and agree with each other on every point. I always find it agreeable to agree with everybody who speaks at the same time I speak, but I am not going to agree with Mr. Stillwell with regard to his suggestion of a six-year course in engineering. Dr. Swain, I saw right off, knew I was not going to agree with Mr. Stillwell, and I believe Dr. Swain does not agree with him either. We may agree, however, more nearly than would appear on the surface. I do believe absolutely with Mr. Stillwell that we should not so confine our education for engineers in the college as to have them limited to technical studies. On the contrary, I am a strong advocate of a more liberal course. But I do not believe that the college is the only educational agency. Far from it. If it were, then we would have a very poor lot of engineers.

I do not want to be misunderstood. I do not think that the college is actually *necessary* for the brilliant man, or the man who can work 26 hours out of every 24, to get his education. It is the best preliminary training, in my opinion, for the average man, but I do not care who he is that goes to college, if he depends on that education he will never be an engineer in the true sense of the word. He must still graduate from the school of experience. My point about the four-year course, the two-year course, preliminary to the four-year course, or the six-year course, is that the argument is generally made, as far as I have heard it, that we need to increase the length of the college course in engineering to keep abreast with the progress of engineering science. Then how many years shall we increase it, if we are going to cover the field? Will two years more do it, or four years, or six years, eight years, or ten years, or shall we keep a man in college until he is seventy years of age? He will not keep up with the progress of engineering science even then. In other words, while the man must be trained broadly in the fundamentals of engineering science, yet the practical engineer to be efficient must be a specialist, and the sooner he gets out, after he has learned the fundamentals, the more quickly and more efficiently he will acquire his training as a specialist. That is my opinion, based on my observation before and since I have been president of Stevens Institute of Technology. On the other hand, I believe today in America we are distinctly at fault, for the boys come to us at college at eighteen years of age, knowing far less than they ought to know, and this because they have been crowded through so many subjects that, as a class, they are not thorough. I believe that our public schools and preparatory schools generally can do more than they are doing if we could only recognize what is the truth, and recognize what is not the truth, with regard to education. Thoroughness in the fundamentals should be the basis for all education, and failure here is not compensated for by a smattering of many subjects.

It seems to me that in considering the status of the engineer today there is a broad responsibility to be considered. And I believe, based on a rather wide experience in engineering and outside of engineering, the problems to be settled in this country today, if this country is to continue in prosperity and not to have practically a revolution, are many of them, if not a majority, connected with engineering and the industries. If that be the case, what particular training should be peculiarly valuable in the settlement of these problems? Certainly the men who are trained in engineering and industrial management. But still, as has been pointed out to you by the last speaker, it is the engineer and the industrial worker who is least considered today with regard to law making and the settlement of these problems. It is very interesting to be told the proportions of the different professions represented in our Congress. For instance, 75 per cent of the membership, as we have been told, is represented by the legal profession. There is only one engineer. I notice, however, with a good deal of interest, that there are two undertakers in the House of Representatives. I do not know how the previous speaker looks on that. If he thinks they are out of place, I disagree with him. I would not mind seeing the proportion largely increased.

As to the way our laws are made let me quote from an address made last year by a lawyer, lawmaker, and statesman respected by all, irrespective of party, Elihu Root: " We make too many laws. Our national and state legislatures passed 62,014 statutes during the five years from 1909 to 1913 inclusive. During the same five years 65,379 decisions of the national and state courts of *last resort* were reported in 630 volumes. Of the statutes 2013 were passed by the national Congress; and of these decisions 1061 were rendered by the Supreme Court of the United States.

" Many of these statutes are drawn inartistically, carelessly, ignorantly. Their terms are so vague, uncertain, doubtful, that they breed litigation inevitably."

We talk about the great achievements in engineering, and I think, as a rule, even we engineers are apt to think of the influence of our profession as exerted through these great achievements, like the Panama Canal, the building of our great subways, the great hydroelectric installations, etc., but do we reflect that practically every thing in our daily life is involved with engineering? If we walk through the streets and look into the shop windows, no matter what kind of a shop it is, we have evidence of the engineer's work in one way or another. If that is so, why is it that in connection with the laws that are made to govern or misgovern these people, the engineer should not be in evidence more than he is? It is partly his own fault, I am afraid, partly because he has not felt that he was called upon to take up the duty of doing his best to influence public affairs.

I have had occasion many times to talk these matters over with engineers, and have had them say to me over and over again: " Well, that is not my business." It is their business, and it is our business, and distinctly so; we distinctly have the responsibility, for our training makes us peculiarly capable of solving some of these problems. The responsibility must accompany education and training; and before we complain too much as to present conditions we must recognize that we ourselves are in part responsible. It is not enough that we are ready to serve, but if necessary, we must force ourselves into the situation.

Now, how about these people who go to our legislative halls and say they reflect the will of the people? It is perfectly ridiculous. If a man goes to seek an advantage and by every sort of trick manages to make his point, does he reflect the attitude of those who surround him? Many of those who have been made his tools would not think of adopting his methods or his ideals. That sort of argument is funny, as the speaker said, but it is very far from convincing.

How about this joy of achievement? Again, should we not look at the little things as well as the big things? Should not we as engineers be more prepared than we are to get joy out of doing our work well all the time, in effort to keep up the standards, even where this involves repetition. Is there not a field in this country today with regard to this pleasure in doing work well? I know there is in the schoolroom, not only in the colleges, but in the graded schools. There is a distinct lack of the joy of achievement in the case of too many of our scholars.

There is at least one gentleman in the room who would be disappointed if I did not refer to the commissions. Why should the engineer be excluded from membership in the commissions? They are hired to serve the commissions, to do their bidding, but it is rather the exception when an engineer is appointed as a commissioner. Personally I believe that the present tendency towards commission control is absolutely in violation of our form of government. Again, I shall be misunderstood, I fear. I believe there should be commission regulation, not commission control. I believe that if engineers had been on these boards from the start there would be less tendency than has recently been exhibited to usurp the three functions of government which, according to tradition and according to law in many of our States, is in violation of our form of government, namely, that the one body should exercise the three functions of government—the legislative, the executive and the judicial. These commissions all do exercise these three functions. I have had it stated to me by some of the commissions that the courts are above them, and so control the judicial function. Do not the lower courts exercise judicial functions, although they are subject to the court above them?

Judge Prouty in an address delivered about a year ago, after serving many years as the Chairman of the Interstate Commerce Commission, and necessarily having had a large experience, while declaring his warmest admiration for his own profession, which he says is the greatest profession in the world —of course, there is always a difference of opinion in such matters—said he had come to the conclusion as the result of his experience that the engineer is *the* man for membership on these commissions, and then he states some things in which I agree with him, and some in which I do not. For instance, he states that engineering problems can be solved by mathematics alone. Nothing could be further from the truth, in my opinion. As Mr. Herr has stated, there are many other things besides mathematics to be considered, and one of the things which has to be used to a large extent in engineering is common sense, something that is not too much in evidence in our legislative halls today.

Judge Prouty then goes on to make an argument in favor of putting engineers on these boards. I do not mean that he favors putting engineers exclusively on these boards, nor do I think that the different vocations, the different activities, in life should be represented on these boards, and if a single engineer is sufficient then a single lawyer is sufficient. These boards should be made up of common-sense men, broadly trained, broad-minded, fair, and competent as investigators, and this irrespective of their professions. I do not by any means advocate putting engineers on these boards only because they are engineers, any more than we would advocate placing a lawyer on the bench simply because he is a lawyer. Judge Prouty himself in this statement says that the lawyer, naturally, is not of a judicial turn of mind. He is prone to be an advocate; whereas the engineer is prone to be judicial in his consideration of questions. I have often thought in connection with my experience with these commissions that if I could not do better with the law questions that are brought forward than the lawyer commissioners do with some of the engineering questions, I would retire from the witness chair.

Another member of the Interstate Commerce—who, by the way, is not a lawyer, but a professor of economics,—has come to the same opinion as that held by Judge Prouty, with regard to the desirability of having well-equipped engineers on these commissions. I confess I should expect to secure this admission from experienced members of the legal profession sooner than I would from theoretical economists.

As to this question of honesty. While we have always had the Ten Commandments to guide us we have of late years had them served up to us in many different forms, and generally as if they had not been brought to our attention before. Is it not true that the legislators and others in power today in this country are conducting themselves, and trying to conduct us, as if there was no real honesty in the country outside of the government circle? Is it not a fact that at every turn, business and enterprises of all sorts are being put on the defensive? It seems to be assumed that business men must be treated as if they were dishonest until they can prove to the contrary. Because there is dishonesty, and there always will be until the millennium—and in my humble opinion that will not be ever on this earth—because there is dishonesty, then must we regulate our affairs on the supposition that all are dishonest? We must put faith in the men who are doing the work of this world. I have had a pretty broad experience in many different lines. I commenced at it when I was very young, and I have been thrown in contact with men in many different lines of work, and I am glad to be able to say my experience has been that the great majority of men I have come in contact with are honest. There are dishonest men and we must guard against dishonesty as we find it in the minority, but that does not imply that every man with whom we do business for the first time must be put down as dishonest until he proves that he is honest.

Now, one of our greatest troubles today, in my opinion, is that because we have discovered dishonesty in some, we must regulate our affairs on the theory that all are dishonest. Personally, I object in my business affairs to the application of this theory.

Another thing: I believe that today we are submitting too timidly to this excess of regulation and control. While I do not believe it is for us to try to influence public opinion by devious methods, I do believe it is our duty to educate the public through frank statements of fact and arguments thereon reiterated as may be necessary; always being sure of our facts, and then having the courage to state them, even though we may fear that our personal interest for the time may be thus endangered.

Just one word in conclusion: I believe that engineers, are better qualified than the men of any other one vocation or profession to help in bringing back this country to a sane regulation of its affairs.

ADDRESS OF GEORGE F. SWAIN

IT IS an opinion that is very widely held, and particularly among engineers, that the engineering profession is not appreciated at its full value, and that the engineer does not receive the recognition in public life and as a leader that his attainments entitle him to. In times past I have not hesitated on various occasions to raise my voice, feeble though it may be, in support of that proposition. I have not changed my views at all, and I agree with what has been said by previous speakers this evening in regard to that matter. However, it seems to me that by emphasizing continually what the engineer ought to have, we may possibly overdo somewhat that aspect of the matter. I am, therefore, going to ask you tonight to take a different point of view with me for a few minutes, and to consider, if the engineer has not received proper recognition, what the causes for this are, and how the existing condition may be remedied.

Of course, as a purely professional worker, the engineer is always necessary, and he will always be called upon to do engineering work. Moreover, statistics show that the remuneration which engineers receive is, on the average, as large as that received by members of the other professions. It is a question of supply and demand, and the engineering profession is not overcrowded. I feel certain of this from my experience in having turned out a great many young men year after year, and having placed them in positions.

Moreover, happiness and content, real success, service to mankind and to a man's family, do not depend upon money, and are not measured by dollars and cents, and can be obtained just as well when the remuneration is moderate as when the remuneration is very large; and engineers, as a rule, I believe, receive compensation sufficient to enable them to live comfortably.

Furthermore, in recent years the respect paid to the engineer, as well as his financial remuneration, have greatly increased. Engineers now frequently receive very large fees, fees that 25 or 30 years ago would have been considered almost out of the question. However, those fees are not as large as those sometimes received by lawyers or doctors, for the simple reason that the engineer does not appeal to sentiment, which is so potent a factor in the other professions. I presume that fear, love and avarice are the most powerful emotions of the human being. The law appeals to all of them; medicine appeals to fear and love; engineering appeals to none of them. Another potent factor in the human being is vanity. Architecture appeals to vanity. The architect can easily persuade his client to put up a costly and luxurious building, upon which he receives his percentage, the percentage increasing as the work is less and less necessary. The architect rightly puts a tax on luxury.

However, all of these matters in regard to the professional services of the engineer will take care of themselves. We are chiefly concerned here with the status of the engineer as a leader in the community, as a moving force, as an administrator or executor, who leads on the solution of great problems.

The suitability of a man for leadership depends upon two things—his knowledge and his personal qualities. Most of the great undertakings today, as has been said by speakers before me this evening, involve engineering; most of them, to a very great extent. Everybody recognizes this. We all know that we live in an age of applied science.

But law and business are equally necessary in the treatment of all of these great undertakings. There is no more reason, inherently, and no less reason, why the engineer should lead and be the employer, any more than why the lawyer or the business man should lead and be the employer. It gets down, therefore, in the end, to the matter of personal characteristics, as questions of this kind generally do. The man with the personality, if a lawyer or a business man, can easily lead, and can hire the engineering brains and knowledge, just as the engineer, if he has the personality, can lead and can hire the legal and the business brains and knowledge.

If, therefore, the engineer does not lead, it must be because he lacks the personal qualities of leadership; and if he lacks these personal qualities, he ought not to lead. There is no mystery about it, no injustice. By personal qualities I mean character, presence, tact, ability to handle men, breadth of mental vision, mental training.

Now, some of these qualities are inherent, and all may be developed more or less by training and experience. There is no reason to believe or to assume that one class of men in a community, in the same country and at the same epoch, are inherently superior, in regard to personal qualities, to any other class. Have we any reason to suppose that engineers are inherently superior to the members of other professions in this country? It does not seem to me that we have. What indications there are might be considered to point the other way.

This is a matter upon which a person cannot speak at all positively, or dogmatically, but I have talked with a good many college graduates as to what becomes of the men in their classes and I have been rather interested to find that they almost all tell me that the ablest men in their classes go into the law or into business. One thing, therefore, we must do is to try to do whatever is possible to induce the young men who are able, and of good character, to become interested in engineering, and to embrace it as a profession. We can all of us do something in that direction.

The problem is then reduced to this further question, whether the personal qualities that come by training, or are developed by training and experience, give to the members of the engineering profession preeminent qualifications for leadership. Those qualities which are most influenced by training and experience are mental grasp, ability to reason correctly, capacity to discern truth and a desire for attainment, and also the ability to deal with the human element. Now, it is generally claimed that the engineer should be particularly fitted, not only by his knowledge, which matter I have already referred to and disposed of, but because of his training, in ability to think straight, in breadth of view or grasp, in desire to get at the truth, and in the ability to discern the truth when he has arrived at it.

Now, how true are these claims? Do engineers think straighter than lawyers or business men? No positive statements can be made on a subject like this, and there are of course many exceptions to any statement that can be made, but I doubt whether engineers as a class think straighter than lawyers, especially, or the well-trained and experienced business man. The training of the lawyer in finding the exact meaning of terms is one of the most important factors in making him think straight. We all know how many misunderstandings and errors in reasoning come about because the exact meaning of the words or terms we use are not quite clearly understood. Ambiguity is one of the main sources of error in reasoning. The lawyer is continually concerned with getting at the exact meaning of words. In drafting statutes, in drawing wills, in all the varied work that he has to do, this is one of the practical courses of discipline which he goes through, and there certainly could be no better discipline.

Moreover, no man understands a question if he can only state it from the positive point of view; he must also be able to state it from the negative point of view; he must see not only what it *includes*, but what it *excludes*; he must see not only the arguments in favor of it, but the arguments against it. In that matter also, the lawyer has a most excellent training. When he assumes a case he puts himself in the position of his adversary and exerts his wits to the utmost to discover the weak points in his own case. He tries to discover every argument that can be brought up on the other side, and then prepares himself to meet them. I somewhat question if engineers in their experience go through quite as good a mental discipline as that, or whether in the school room they get anything that is quite as good a mental discipline.

I think, therefore, the legal training and experience, on the whole, probably trains men better to think straight or to reason logically, than engineering training. The single objection to the legal training is one that has frequently been mentioned, and has been previously referred to this evening, and that is that the lawyer is apt to become an advocate. But still we all know that there are many, very many, capable, high minded lawyers who will not take a case unless they believe that they have the right on their side. Moreover, in human affairs, there is almost always something to be said on both sides of every question, and the lawyer who undertakes a case, should simply have for his object to see that the arguments on the side of his client are presented as strongly as possible, leaving it to the judge or the jury to decide on which side the right is to be found. It is not always a simple case of being in the right or in the wrong; it is more often a question of presenting fairly one side of a two-sided argument.

It is undoubtedly true, however, that there is a seamy side to the law, and that large numbers of members of that profession are dishonest, many of them mere blackmailers or ambulance chasers. To this class of men there is no parallel in the engineering profession, so that, taken as a whole, I believe, as I have frequently stated, that there is no more honest body of men than the members of that profession. There is abundant proof, however, that honesty of purpose and a desire to arrive at the truth may be misdirected, and that those qualities will not result in leadership unless combined with judgment, breadth of view power of logical thinking and the ability to distinguish truth from error.

Now, how about breadth of view? Can we say that the engineer's training and experience gives him a greater grasp, a greater mental breadth of view, than that of the lawyer or business man? Here again there may be doubt, but I similarly question whether today, and in the past, the training of the engineer has given him as much grasp and breadth of view as the training of the lawyer and the business man. I am afraid that the engineer concerns himself in college, and after college, too much with the minor technical details of his profession, does not accustom himself to study large questions, does not take interest enough in the consideration of the great problems affecting the community in general. I know that is so in the colleges. I know that the young men get interested in the purely routine technical details of the studies they are pursuing, and that it is difficult to get their minds away from these things to any large extent. Some men have such breadth of view, and get above the details of their profession, but many engineers seem to lack this quality and find it very difficult to acquire it.

The case with the business man is somewhat similar. I am a great believer in the business man, and I believe that his experience, bringing him in contact, as it does, with law, with engineering, with all the varied activities of public life, is a most excellent training. I should like to see more engineers in Congress, as has been suggested, I should like to see an engineer become the president of the United States, but I should like to see, for once, a really good, broad-minded business man in the presidential chair.

Instead of complaining, then, although it is true, that the engineer is not recognized, I urge that we try to realize, if this is so, that there is a cause for it. We live in a world of natural law. For everything that is, there is a cause, not only in the physical world, but in the mental and moral world; and this cause will always produce its effect. If the engineer is not recognized, therefore, let us see if we cannot find the cause and remedy it.

Among the things which I think we can do, are the following: We may exercise our influence to bring the facts in regard to the engineering profession, its possibilities, the high character of its work, to the attention of our young men in our schools, and to induce the honest and capable young men of the coming generation to embrace that profession. In the second place, we may influence technical education and try to secure a broader curriculum in our engineering schools, with more attention paid to fundamental principles and less attention to the technical details, which the graduate must learn in order to master his profession, and which he can learn a great deal better in the field after he graduates than he can in the school. Let us insist on a training of our engineering students in the English language, so that the engineers of the future shall not only be able to speak and express themselves clearly and lucidly, but may be able to write a proper report, and to impress upon people with whom they come in contact, not only that they are qualified in their engineering specialty, but that they are able to mix with men and to deal with large questions in a comprehensive way.

I agree entirely, with what has been said in regard to mathematics. I think the fact that engineering is to so large an extent a mathematical subject is one of the main reasons why the engineer is not recognized. In my opinion, there is scarcely anything that tends more to narrowness of view than dealing all the time with problems that can be solved only by rigid mathematical processes, because the great questions which confront us, even in engineering, are not mathematical questions; the data are shifting and variable, and the human element comes in; therefore, the man who is accustomed to solve his problems by mathematics, and can only do the solving in that way, finds himself at a loss in the practical affairs of life, where mathematics do not apply. We should further seek to broaden the minds of our engineering students, as well as our own minds, by the study of history, literature, psychology and other subjects which give a broad outlook upon life.

I urge, therefore, that in these ways we help to make ourselves and the engineer of the future possessed of the personal qualities of leadership. We may rest assured that if we are possessed of these qualities, leadership will come to us.

ADDRESS OF HENRY G. STOTT

I FEEL that it is not necessary for me to apologize to you tonight when I say that I am going to be very brief. The hour is so late, and so many weighty matters have been presented to you tonight by the eminent gentlemen who have spoken to you, that I am quite sure what I have to say can be put before you in a very brief time.

I think that the present status of the engineer is quite satisfactory when we find on our platform tonight two engineers who are now presidents of two of our great corporations in this country.

There is one feature of the status of the engineer in this country, however, which is extremely unsatisfactory and absolutely unfair. I refer now to the many engineers who are employed by the United States Government. You hear of Major So-and-So, Colonel So-and-So, and Captain So-and-So, having charge of such and such a piece of work, a great piece of engineering work; but you never hear a word of the poor civil, mechanical or electrical engineer, who has actually done the work, and probably planned the whole thing. Our army engineers are very capable men, but they secured their high positions, as a rule, as executors, and did not do the actual engineering. That is one point on which we should all aim to help out our brethren who are employed by the United States Government, to secure a better recognition of their services. That is really a very important thing, I think, for engineers to remember, and they should keep it in mind wherever they can bring any influence to bear on the Government officials.

About seven years ago, when you honored me by electing me President of this Institute, at the time when it came for the President to sing his " swan song," I made some remarks on the " Evolution of Engineering." In that address, which was given at Atlantic City, I quoted one of the oldest definitions of engineering that we have, that of Thomas Tredgold, who, about eighty-seven years ago, gave this definition: " Engineering: The art of directing the great sources of power in nature for the use and convenience of man." That is a very powerful definition and still holds to a great extent today. However, I showed in my address to which I have just referred that, due to the evolution of engineering, we are constantly developing new specialties, that as the art developed and the particular branch which a man was working on became more important, it became necessary for someone, and perhaps many, to devote their entire attention and study to that one branch. We have at least fifty distinct and entirely separate branches of engineering today. While it is very necessary for a man to have a general knowledge of engineering, and of other subjects, in that connection I always think of a musical comedy which was presented in New York some years ago, in which one of the performers rendered a song or recitation, and in it he told about his father, who was a " musikir," but he could not play the violin because he had too many knuckles on his fingers, and could not play the trombone because he did not have wind enough, etc., and he finally settled down to play the base viol. The moral which the performer drew from his father's struggle to play the different instruments was that "you cannot play every instrument in the band." There is much truth and philosophy in that, and it stuck in my mind. We should specialize in some particular branch, and remember that we cannot play every instrument in the band. There are at least fifty different instruments in our band, and no man can play them all.

The developments of recent years, however, have brought us face to face with two types of engineers, those who specialize on one, or possibly two subjects, as one class; those men, I think, reap their reward in their achievements rather than in any great fame which may come to them. They certainly in their achievements have great reward. In another class are those who come to certain stages of endeavor by a process of natural selection, and naturally adapt their engineering principles to executive positions. We have on the platform tonight several notable examples of that kind. I take it that as long as men are not all made alike—no matter how evenly they may start with the same education, they all have different characteristics—and each one must be developed along the line of his particular talent, so that while some may specialize, others will generalize.

And so, as in finishing up my address at the Convention at Atlantic City, I will close with my own definition of engineering, which I made at that time, as being rather more applicable to the present development of the art:—" Engineering. The art of organizing and directing men and of utilizing the forces and materials of nature for the benefit of the human race."

ADDRESS OF J. J. CARTY

THE ENGINEER does not work in isolation. Like his fellows in the other learned professions his work is done in co-operation with those within and without his own profession. His work may be done through conscious co-operation, as in a corporate organization or learned society, or it may be done through that co-operation which he, like all others, exhibits as a member of organized society, and which is often most intense and effective when he is attending strictly to his own business, with no thoughts of co-operation in his mind.

From the dawn of engineering the work of the engineer has had to do with men as well as with things. The first rude implement shaped by the hand of man was designed to divide man's labor with him. In creating the first industrial and agricultural tools used by mankind the primitive engineer worked out a problem in organization, for the problem of organization is the problem of the division of labor. Labor may be done wholly by men and divided up among them in various ways according to their abilities, or it may be divided so as to be done partly by animals or partly by machinery provided by the engineer.

On account of the physical nature and oftentimes the monumental character of great works of engineering, the material side of the engineer's work has, until recent years, been its dominating characteristic, not only in the minds of the public but to a large extent in the minds of the engineers themselves. . But a change has taken place. It has come about so rapidly and so imperceptibly that there has not been time even for the engineer himself to realize it, notwithstanding that to these changes he has been perhaps the greatest contributor.

The pure scientist, searching the unfathomable depths of nature to discover the wonderful truths there to be found, produces the raw material with which the engineer, with the powerful aid of his close ally, the chemist, constructs agencies which do so much to magnify the returns from the labor of man. From the dawn of history the work of the engineer has been to lighten the labors of man and to provide him with means of defense against his enemies. That these agencies provided by the engineer could be used for offense, as well as defense, and that they have been used in unjust, aggressive wars is the testimony of history. This evil is not to be ascribed to the work of the engineer. It is but a part of the crime of those who are responsible for waging an unjust war.

To understand the status of the engineer, we must appreciate his activities in war as well as in peace, and when peace comes again, and let us hope it will not be long delayed, astounding will be the story that will be told of how the agencies provided by the engineer have shared with man the labor of destruction.

Fortunate it is that we are not now compelled to consider the consequences of the engineer's efficiency in war, but that we can dwell upon the more salutory results of his efforts in the arts of peace.

During the last forty years, the increase in the means of transportation and communication, combined with the multiplication of improved labor-saving machinery in agriculture, mining and manufacture, which is so largely due to the engineer, has made possible in a higher degree than ever before that division of labor and that high state of differentiation in our industrial and commercial organization which are the mark of progress.

Everywhere that machinery is employed, the work of the engineer is plainly evident, even to the superficial observer. It can be allocated to a concrete, definite, physical thing. It is not so easy to see that in the design of this machinery the engineer had to consider his problem broadly as a problem in the division of labor, and that he had to determine at what point in the economic scale human labor could properly be superseded by that of the machine.

By such methods as these, the engineer long ago learned what is not yet sufficiently understood, that the problem of introducing a labor-saving machine is not solely a mechanical one. In addition to mechanics it involves economics as well as methods of operation. To the untrained mind the design of a machine to perform work formerly done by hand seems all that is required, but to the engineer, who is trained to consider these problems comprehensively, such a machine, however well it may operate, is not a labor-saving machine until the total annual charges lying against it are less than those which would be incurred if the work were done by hand. In this comparison, of course, the same quality of output is assumed. Unless equally good work can be done by the machine at lower annual charges, it is not a labor-saving machine, but rather a labor-increasing machine, substituting one kind of labor for another and more of it; but because this increased and substituted labor is performed in the mine, or at a distant factory, or elsewhere, it is not recognized by those minds which are capable of dealing only with simple, concrete things before their eyes which they can see and touch.

It is in the manifold nature of such problems as these that the ideals and imagination and those other mental processes of the engineer are brought to that high degree of development which lies at the foundation of all that is great in his achievements. The work of the engineer calls first for a correct ideal. While, as in other human affairs, it is not often that he attains an ideal solution of his problem, he understands the value of a correct ideal toward which, by the aid of an accurate and trained imagination, he directs his efforts.

In a distinguished way the work of the engineer, to be successful, must follow strictly in accordance with nature's laws. Before a human tribunal it might be proved by specious argument that an inadequate structure will sustain a maximum load or will withstand the severest action of the elements, but in the court of nature, before which all of the work of the engineer is ultimately tried, nothing will prevail but absolute compliance with its inexorable laws.

The historian of the future will say that perhaps more than any other class of men the members of the engineering societies which are represented here tonight and their fellow engineers elsewhere are responsible for the marvelous transformation which has taken place in the material conduct of human affairs during the lives of those now living.

This change has manifested itself in a striking manner in the growth of large organizations in all parts of the world. In communities and nations, as well as in corporate organizations, the same tendencies have been at work. Where formerly, units acted more or less independently and in isolation, they are now brought effectively into an organization which is nothing more than systematized division of labor between men and mechanism. All of this is made possible by the perfection of means of communication and of transportation of goods and people. Without these means co-operation between distant units would be impossible and co-ordination of men and machinery now effected over distances of thousands of miles would again be reduced to those primitive forms of control which can be used only when the units are close at hand, in office or factory.

This process of growth and differentiation which the engineer has done so much to promote has produced its effect upon the engineering profession itself. Engineers have increased in numbers and their work has been divided into branches. To the civil and mining and mechanical we have added the electrical and the chemical, and the electrochemical. Each branch has in turn thrown out from itself other branches until we have so many different kinds of engineers that I will not attempt to give the list, which includes farm, public relations, efficiency and commercial engineers.

With such a great growth in the number of engineers and in the importance and extent of engineering, it is inevitable and but a sign of progress that these differentiations should occur. Forty years ago there was no electrical engineer. Now electrical engineering is divided into specialties and even subspecialties. At the time of the Centennial Exhibition at Philadelphia there were no telephone engineers. Today in this country alone they are to be found by thousands.

It has been said that efficiency engineering is but a meddlesome interference with factory management; that commercial engineering very often contains no engineering whatever; that the farm and public relations engineer are but absurdities, and that some action regarding the abuse of the term "engineer" should be taken by the National Engineering Societies. But it seems to me that affairs are not so bad as all this; that there is much that is commendable in all of these movements; that they should be allowed to develop until they have assumed definite shape, and it can be seen whether they may not represent some most important activity to which perhaps only the wrong name has been applied. Such growths as these, if not fit to survive, can safely be left to that pruning process which nature sooner or later applies to all that is unfit.

There is no doubt that in the sudden growth of organization in mine and factory and on the farm and in commerce and transportation and communication, the engineer has often been admirably qualified to make that systematic division of labor among men, and between men and machines which constitutes modern organization. When viewed as a problem in the division of labor as between man and machine how natural and easy has been the evolution of the efficiency engineer, who is really dealing with the problem of management, and who is calling his work by the name of " scientific management " instead of " efficiency engineering." It will be a great day for progress when "scientific" management can be merged with "common sence" management, each droping the adjective and becoming plain *management*.

There is no doubt that some of the engineers with adjectives have been over-running the territory and encroaching upon the provinces of other branches of industrial and commercial activities, and that under the name of " engineering " they have been performing functions foreign to that profession. It is safe to say that this is because the sudden increase in the complexity of modern organization brought about by the use of scientific methods and mechanisms has obliged the manager to give more and more attention to scientific and engineering matters. Because of his lack of familiarity with these new changes he has been obliged to call to his aid the engineer and has been led to call by the name of " engineering " many activities which are really those of management and which, with the growth of the science of management, will in due course be called by their proper names.

In this there is a tribute to the engineer and at the same time a warning. It is coming to be recognized that the experience with men and things to be obtained in the practice of engineering is a valuable ingredient in that complex compound of which successful management is composed. The warning to the engineer is to check his activities as soon as he finds they are encroaching upon the province of other professions and other departments, to call things by their right names, and to recognize that within his own province there lies a career exceeded in usefulness by none of the other learned professions. By so doing he will best prepare himself to receive that recognition outside of his own profession which, at the dedication of this great engineering building, was prophesied for him by Dr. Hadley, the President of Yale, who said:

> " We have outgrown the day when a little common sense was sufficient for managing the affairs of the nation. They are become too complex and this complexity gives the engineer—if he will add to his training in mathematics a training in ethics and political economy and the fundamental principles of the law—an opportunity such as never before existed to claim and receive the position which rightfully belongs to him.
>
> " We celebrate today and we are justified in celebrating the recognition of science as a necessary guide in the conduct of the material affairs of each man's business. Half a century hence, when our descendants shall meet in this building, or some yet greater building, I am confident that they will celebrate a yet greater thing, the recognition of the right of men of science to take the lead in enlightening the thought of the people on public affairs and the responsibility of filling the higher positions in the service of the commonwealth."

Although these words were spoken from this very platform less than ten years ago, yet in that short time so far has the status of the engineer been advanced toward the ideal set forth by President Hadley, that I am sure if he were here to-night he would not place that day which is to be celebrated so far away as half a century hence.

DISCUSSION ON "ELECTRICAL FEATURES OF THE UNITED STATES RECLAMATION SERVICE" (NEWELL), PHILADELPHIA, PA., OCTOBER 12, 1914. (SEE PROCEEDINGS FOR OCTOBER, 1914)

(Subject to final revision for the Transactions.)

Paul Spencer: Upon hearing the paper read, I was struck with the advantages of having someone supply you with money without interest charges, and being able to make contracts on which you could shut off power whenever you did not have it, or did not wish to supply it. Under those circumstances, I can understand that you might be able to sell your surplus electricity at the price stated. The low rates can only be considered as due to those extremely peculiar conditions.

Ralph W. Pope: It is not quite true that the cost of installation is given to the owners of the land, or that they do not pay the cost. That is all figured out, and included in the price that they pay for the land, and it is expected that the installation will be paid for by the consumers in the course of twenty years. As to the low rate, there is absolutely no use for the power in winter. The intent of the irrigation plant is to supply water for irrigation, and no pumping is required during those months when the low rate is given. It is simply a question of competing with coal, for heating, and this is possible where coal is $7 a ton.

I had occasion to inquire about this matter of taking up land, and the replies I got were conflicting. One question that I asked a man, was whether they found men who were willing to take up these small tracts and pay the price, whether or not they were farmers who were accustomed to operating small farms. He said that was one of the difficulties that they had to contend with, that they did not find people ready to take up the land under those conditions. Another man that I met further on, said that where he was, they had had no difficulty of that kind, that there was no trouble at all in finding people who were willing to settle under those conditions. So, there you have the two statements, probably one coming from one part of the country, and the other from another part.

It is certainly a very interesting subject, and since I have learned more about irrigation, I realize that it might have been used in our eastern States to great advantage, and we would have less growling about a drought, such as exists now in many parts, if farmers had utilized the water which is available for such purpose. Of course, this is not always the case, because we do not have the snow-capped mountains in the East to furnish water through the action of the sun, so that the conditions are somewhat different.

J. E. Kershner: I was looking over the table on page 1585, and, a little contrary to a previous speaker, I cannot say that I was struck with the cheapness of the power, except, perhaps, in two instances—0.268 cent and 0.126 cent per kw-hr. If you except those two cases, we can buy wholesale power cheaper than any of the other figures, from Pennsylvania water power companies.

P. M. Lincoln: The extremely low rate for heating, given in the table on page 1587, is possible simply because during the winter time they have no other use for the power, and the only market for their power is for heating purposes. The load factors are given on page 1585. Those prices apply for the load factors actually given. You will notice that where the load factors are high, the prices are low, and where the load factors are low, the prices are high.

H. A. Hornor: There is one fallacy spoken of in the paper that we all know very well, but it seems to me that it is important from the standpoint that the public does not seem to understand it. I refer to the question of transformer losses. I have heard it stated by an engineer of one of the most efficient central stations in the eastern part of our country, that the coal consumption on Sunday about equalled the normal daily coal consumption during the week, due simply to transformer losses. I think the public fails to appreciate that the central station has to carry a transformer load in order to supply its customers with reliable power.

Vladimir Karapetoff: Mr. Newell in his paper does not claim to bring out anything new from an engineering point of view. On the contrary, he emphasizes the fact that the construction used is standard as much as possible. Nor is the paper remarkable for the size of the plants or the hydraulic head used. We have a great many plants in comparison with which the plants he describes are mere dwarfs. But the paper is of great interest because it gives examples of successful hydroelectric work done by our government. Those of us, who, like myself, are believers in government ownership and operation of public utilities, welcome a paper of this kind, because it furnishes us with valuable material for our argument. We have very little inkling of the successful engineering work done by the government. This afternoon we listened to an account of the highly successful work done by the Navy Department in cooperation with private concerns. I welcome Mr. Newell's paper as showing that there is no reason why the government should not engage in a hydroelectric project and bring it to a successful end.

There are just two points about which I would like to ask. On page 1585 the cost in cents per kw-hr. is given. Is it not rather misleading, to give the cost per kw-hr. in a hydroelectric station? The first plant, for instance, operates at an annual load factor of 12.7 per cent, and the cost in cents per kw-hr. is 0.81. The plant could furnish, say, five or six times that amount of power, with very slight increase of expense, for additional personnel, and the cost in cents per kw-hr. would be, say, one-fifth of that given. In other words, it seems to me that the last column does not really give the cost, unless it is always quoted in connection with the annual load factor. There ought to be some other basis for comparison. Of course, one basis is the cost of the original construction, per kilowatt capacity.

Another point is this: Some years ago I was asked to investigate into the possibility of certain electrochemical processes in this country that require cheap power, and particularly one of fixation of atmospheric nitrogen, a problem which appeals so much to our imagination. At that time I could not find any place where power could be purchased at a figure that would warrant such an installation. After reading these wonderful figures of cost, I should like to ask those who, like Dr. Hering, understand about electrochemical processes, if nitrogen fixation, or some other fertilizer process, could not be run intermittently during the winter months in connection with one of these plants?

Carl Hering: It seems to me that answers itself, provided such a process can be interrupted; in fact, at a recent meeting of another society, I cited that very case as one in which power could be "stored" more cheaply and better than it can be stored as water in reservoirs. I refer to those electrochemical plants which can be run when the water power exists, and can be shut off when it does not exist. In that way the product can be produced while the water is flowing, and can be sold at one's leisure, which is in effect a process of storing the energy. There is no doubt that this can be done with some electrochemical processes, but not with all of them.

In connection with what Prof. Kershner said, I notice at another place in the same table, on page 1585, that these costs are stated to be those at the switchboard, and not for power delivered to the premises. It is one thing to generate power, and another thing to transmit it and deliver it; the cost of transmission is sometimes great. One would have to run his own lines to the switchboard, to use the power at these rates. If the cost of distribution is added to the figures in the lower part of the table, the energy is by no means cheap.

Mr. Bender: I would like to ask, also, in connection with those figures, if interest is included in those costs? That would be another item to be taken into account.

P. M. Lincoln: I am not sure of that, but I think interest is included, but at a very low rate, a rate at which the government can borrow money.

H. Goodwin, Jr.: Mention has been made of the use of water for irrigation in the orange orchards in Southern California, and it might be of interest to try to get a little nearer to the point of view of the men operating those orange groves. Two years ago I was at Santa Paula, about 100 miles north of Los Angeles, at the oldest lemon grove in Southern California, which is now growing many oranges, too. They own the water rights of a small stream which supplies sufficient water for irrigation all through the irrigation season. The grade at which the water reaches the grove is the highest of the level section, but above that are many acres on a steep hill which were used only for hay. (Their hay is a mixture of barley and oats, and not our timothy and clover). There was so much money in oranges that they were considering putting about 50 acres of this land into oranges. To do that they would have to pump water to the top (by electric power, of course).

At the rate they receive for such purposes it was found that it would cost them $18 a day for pumping water up over this hill of 50 acres. That was no hindrance at all to them. They went right ahead with the proposition. Eighteen dollars a day is nothing at all to them. But if you tell a farmer here in the east to spend $18 a day for pumping water over his land, so as to double his output, he will tell you you are crazy.

There is another interesting point about the way they use the power. One very large item of expense of which Mr. Hornor has spoken is transformer expense. They avoid this by using 2400 volts just as we would use 110 volts here. All the pumps are 2400 volts. They run the overhead lines on ordinary D.G. glass insulators, come into a little shack through porcelain tubes, erect some current transformers and a meter, put a couple of knobs on the ceiling, and drop down to the motor in the center of the floor. This wiring does not cost them much over $20 or $25, which is a decidedly different proposition from our transformer installation, and other work we have to do in this section. Yet I could not find any case of death by electrocution of any of the men working around these groves.

The point of view of the Southern Californian is so different from our own in regard to spending money on farms, that it should be of interest to us to look at things occasionally from that viewpoint.

F. H. Newell (by letter): The above discussion indicates that the object of this paper has been correctly understood and that it is necessary only to answer one or two questions.

With reference to the taking up the reclaimed land, there has been relatively little difficulty or delay in this, as the public lands are practically given away under condition that the cost of bringing water to these lands, including the expenditures for the hydroelectric power plants and other accessories, is repaid by the land owner within 20 years. The time for repayment was originally set at 10 years but, by Act of Congress of August 13, 1914, it was extended without interest to 20 years. Thus the land owners are called upon to pay an average of only 5 per cent on the principal, not interest, for 20 years and then all payments cease, except for operation and maintenance. The amount paid, however, during the first few years is less than 5 per cent but during the latter years of the 20-year period is as high as 7 per cent, being adjusted so as to make complete payment of construction cost within the 20-year period.

In regard to the cost of lands which have passed into private ownership, the prices set on these have been high, but the inflation has practically ceased, and lands irrigated by the government are now being held at more moderate prices than in the past few years. The difficulty has not been so much that of disposing of the land as in getting it utilized to the best advantage after it has passed into the hands of homestead entrymen or purchasers. The lack of capital and high interest charged on borrowed money has delayed development, but with the gradual growth of the country and increase of small industries made possible by cheap power, there is a steady improvement in agricultural conditions.

One of the striking needs, as pointed out in the above discussion, is that of some method of storing this cheap power, one which may possibly be brought about by electrochemical processes. Here is a field for invention which it is hoped will be entered upon at an early date.

The experience which is being acquired in construction, operation and maintenance by the government of works of this character cannot fail to be of value, particularly at the present time when there is general agitation for enlargement of governmental functions. This paper will have fulfilled its purpose if it has attracted attention to some of the opportunities and limitations of such governmental undertakings.

DISCUSSION ON "ELECTRICAL EQUIPMENT OF THE ARGENTINE BATTLESHIP 'MORENO'" (HORNOR), PHILADELPHIA, PA., OCTOBER 12, 1914. (SEE PROCEEDINGS FOR OCTOBER, 1914.)

(Subject to final revision for the Transactions.)

H. L. Hibbard: I should like to know if the author could tell us something about the results of the tests on the electrical equipments which he pointed out as particularly novel and new, for instance, steering gear, anchor windlass, bilge pumps and ammunition hoists. All those are more or less novel, and I thought perhaps he could give us some actual data from this ship or possibly from her sister ship.

Maxwell W. Day: I think there is a decided advantage in the 220-volt system, as far as the installation of the wire is concerned and also in the size of the controlling appliances, and also to some extent because of its effect on the design of the motors, especially in the larger sizes where commutator space can be saved, but, on the other hand, the motors require more turns, taking a greater amount of waste space for insulation and a greater use of commutating poles, so that for a larger number of the motors there is no saving in weight or expense.

The question of operating searchlights by balancer sets or by other means is something of a problem. It is not extremely easy to determine whether it is better to put in balancer sets and use the rheostats or to use that type of generator which will give practically a constant current. With the 125-volt system there is no particular advantage in this type of generator, because its efficiency is not as high as that of other types, so that there is considerable loss in the machine itself, and the difference in using a rheostat for 125 volts to steady the arc, which might take 65 volts, or the use of a motor-generator set, does not show any great advantage for the motor-generator when we take into account the weight to be carried on the ship, although there might be cases in which the heat developed on the rheostats would be sufficiently objectionable to cause a decision in favor of the other arrangement. But when you come to 220 volts, the case is somewhat different, and in some navies special motor-generators, that deliver practically a constant current and require no steadying resistance for the arc, have been quite extensively used.

The steel switchboard with the instruments insulated from it is German practise. It seems to have some advantages, but, of course, the question of insulation is more difficult than it is with a slate base or panel made entirely of insulating material. But some troubles that have been experienced with slate led the United States Navy to look for other substances, and on motor control panels the use of ebony asbestos wood in place of slate is becoming more extensive. The use of alternating current for the interior communication system is also a German practise, although the Germans use direct-current apparatus also. I do not suppose the experience on the Argentine ships has been sufficiently extensive yet to decide on the relative merits so far as these ships are concerned.

The question that Mr. Hornor raised, of continuous waves as against a spark system of wireless telegraphy, is one of interest and the very successful results that have been obtained with the continuous wave system, both when developed by the arc and by high-frequency generators, have led to the desire to make use of some such system on smaller outfits, such as those used on vessels. But in the first place, there is a little difficulty in conveniently obtaining the short waves from the arc system, and to build a small high-frequency generator for short waves, is very expensive. Further, I understand that the short continuous waves are subject to a greater absorption in the atmosphere than those of the spark system, so that it seems rather doubtful to me that the continuous wave system will be extensively used for shipboard practise, at least in the near future.

I might say a word about the steering gear. As Mr. Hibbard knows, we have not advocated the contactor system for large equipments, but this particular case being one of 220 volts and of comparatively small power, it seemed to come within that range where contactors could be used with satisfaction. This particular system is not exactly what is being used in the United States Navy as regards the follow-up device. The United

States Navy does not use follow-up devices, so that when the steering switch is turned to the right or left, the rudder moves to the right or left as long as the switch is left in that position or until the limit switch cuts it off, while on the earlier systems of electric steering gear, the amount of motion of the motor depended upon the amount of movement of the steering wheel or steering lever. It is rather difficult to make an electric follow-up device, and so in this case, and also in order to avoid adding to what is already an extensive electric equipment, the electric connecting leads between the steering gear itself and the steering stations were omitted and the control is operated by means of the same wire rope or hydraulic telemotor that operates the steam valve, the change-over connections being made in the steering room.

The *Moreno* has not had its trial trip, so that the tests at sea on this gear have not yet been made, and the final equipment on the *Rivadavia* has not had its full test, so that at present no information is available concerning the amount of power required or the general operation.

G. A. Pierce, Jr.: The wiring and the method of installation described were unique in this country and at the time this installation was designed. As Mr. Hornor stated, changes have been going on from time to time from a conduit system, which is not to be desired in any respect, and has been looked upon with suspicion since the early days when the change was made from a wooden molding to conduit. I think there will be no occasion in the future to return to the conduit system, so that as regards the reduction in weight and space and also the increased facilities for inspection, the present form of construction in the *Moreno* is an advancement.

In the distribution of energy we find the same method that has always been employed in this country, that of separate dynamo rooms, with interconnecting bus feeders, necessarily large switchboards, a multiplicity of circuits of small cross-section paralleling each other for great lengths, with a corresponding number of protective devices, and numerous large and cumbersome hand starting devices for motors. The installation of 38 lighting circuits for a total of 3000 lights, or an average of 80 lights per circuit, and the use of 76 miles of wire in the installation of this size, is a continuance of past practise, the advantage of which has long since been questioned in this country.

While there are some innovations in the application of electricity on this vessel, the extreme application is not apparent. The communicating and lighting system compares with vessels of the same dimensions built in this country, and by a comparison of the power installation with other vessels we find but few exceptions, viz., windlass, fire pump, oil engine pumps, electro-mechanical hammer, ozonators, athletic horse, and moving picture machine. There is also in use a power system which appears to have been advisedly omitted in vessels built in this country, that is, the electric forced draft blowers. Since the successful construction of small steam turbines has been accomplished, the installation of electric motors for forced draft blowers results in a waste of space, weight and economy. While we desire to see the unlimited use of the electric motor, it is the speaker's opinion that this consideration will apply to all auxiliaries within the zone of the boiler and machinery spaces, where power is available direct from the boilers without transformation and control of the power is so extremely simplified.

In 1902, when the Russian battleship was constructed in Philadelphia, we had an electric steering gear, electric bilge pumps, ash hoists, and electricity in almost all of these features with the exception of the windlass, fire pumps, oil engine pumps, electro-mechanical hammer, etc., which at that time had not been invented, or were not in use anywhere.

The use of 220 volts, double the voltage previously used, does not result in one-half the cost of wire as would be indicated, but only in the saving of three-tenths, with very little difference in the cost of wiring appliances and practically no difference in the cost of apparatus or labor for installation. The saving in weight follows very closely the same proportions as the cost of material, and when the additional cost and weight of balancer sets with wiring and additional protective devices and switchboard equipment for the control of searchlights is considered, the advantage of this increase in voltage is questionable, particularly in view of the advisability, since alkaline storage batteries have become a commercial success, of installing storage batteries as auxiliaries for lighting and power for each battle unit.

The interior and exterior means of communication of information on this vessel are complete. The ever-increasing growth of this system in a battleship may, however, necessitate its remodeling in a very few months, as it is upon these systems the vessel must depend for its existence. If ready for action its presence must not be known until within range and if caught unawares or disabled it must attempt to escape and the vessel's own smoke or absence of it is employed for this purpose. We have recently learned of an invention to indicate automatically in any part of the vessel the color of the smoke emitted from the stack, and no doubt this system will be added in the near future to the ever-increasing means of communication on naval vessels.

Mr. Hornor has raised some question about the 220-volt lamps. Since the 220-volt tungsten lamps have been put on the market, we have been installing them in our ships, installing them on the bottom of cranes, and if there is anything that gets more vibration and shake than the bottom of a shop crane, it will hardly be found on a battleship.

As regards slate switchboards, I quite agree with the move our Government has made in the installation of composition in place of slate.

There appears to be no more necessity for duplicate dynamo rooms than for duplicate engine rooms. We believe that in the power plant of the future battleship there will be a number of units and a switchboard for supplying power for propelling the vessel and for all auxiliaries and lighting. The lighting and power for a deck or watertight section would be supplied from a common feeder with protective devices only at the apparatus, thus reducing weight, space and the cutting of bulkheads. All motors would be started either by contactors with a master controller or by automatic starter with a push button-depending upon the size and use of the motors. Lighting and power of each battle unit and indispensable auxiliary, such as steering gear, would be supplied by individual storage batteries of capacity for battle, thus reducing the size and increasing the efficiency of power installation.

We believe an installation of this character, in any or all of its features resembling the solution of the electric power engineering problem in large power stations on shore, and having the additional reserve for battle conditions at sea, to be not only a departure, but a decided advantage in economy, weight and space in comparison with any marine installations at the present date. Omitting the feature of electric propulsion, it is my opinion that the present practise can be improved upon by combining the dynamo rooms, combining and reducing the lighting and power circuits, using automatic starters and installing alkaline storage batteries, as previously stated.

Elmer A. Sperry: Mr. Hornor has given us a valuable paper. We find in the last paragraph on page 1564 " that any gyro with only two degrees of freedom, *i.e.*, free to move in two planes only," can be used as a compass. Now that is perfectly true; but that compass will only operate on land. When we take such a compass and put it on board ship, where it is subjected to all sorts of movements and motions, we encounter many real problems. These are due to the fact that the compass must of necessity be built pendulous, be supported in a Cardan or gimbal mounting, that it is subjected to acceleration and retardation pressures of the ship on which it is mounted during all sorts of manoeuvres and changes of heading of the ship.

The compasses with which the Argentine battleships are equipped were purchased in 1910 or 1911 from a German manufacturer and contain one 6-in gyro spinning at about 20,000 rev. per min. This was hung pendulous within an annular mercury bowl and was found to give serious deflections in azimuth, resulting from acceleration and retardation pressures and movements of the vessel referred to. No compasses with a single gyro wheel have been built by this concern for the past two or three years, but they have developed a new and very interesting compass containing three gyro wheels set at different angles to each other and coupled by certain links and bell-crank levers, pitman, etc., all the gyros being provided with centralizing springs, and they have adopted a follow-up system substantially similar to the one shown and described in a paper* on this subject read before the Institute last June—see Figs. 7 to 15.

Inasmuch as no representation of this German product has been published in our annals, I am showing herewith, Fig. 1, a vertical section through the machine, giving a view of two of the three gyro wheels, three gyros being located equidistant around the circle. Each of these gyro wheels, it is stated, requires 1.1 amperes per phase at 120 volts, with a three-phase alternating current having a periodicity of 335 per second—in all, 3.3 amperes per phase. This is somewhat in excess of three times the current required by the American-made machine. The combined directive power, or useful function of this three-gyro compass is, however, only about 5/22 of that of the American-made machine.

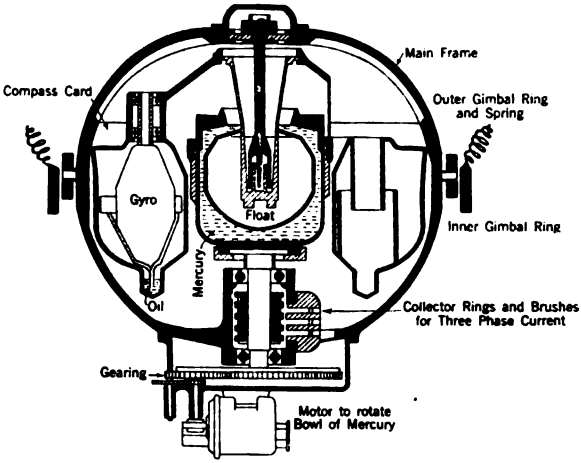
Main Frame
Compass Card
Outer Gimbal Ring and Spring
Gyro
Float
Inner Gimbal Ring
Mercury
Oil
Collector Rings and Brushes for Three Phase Current
Gearing
Motor to rotate Bowl of Mercury

FIG. 1—SECTIONAL ELEVATION OF ANSCHÜTZ COMPASS HAVING THREE GYRO WHEELS

Recent progress in adapting the gyro-compass to battle conditions has enabled the United States Navy to utilize features which do not seem to be present in any other navigation apparatus; among these is the fact that constant corrections which are found to be due to speed and course are automatically neutralized, giving all readings exactly on the true geographical meridian. Moreover, the military value of the apparatus adopted by the United States Navy is considerably increased due to the fact that if the current supply cables are shot away or the current supply ceases for any reason the compass will continue to give true meridional readings with a high degree of precision

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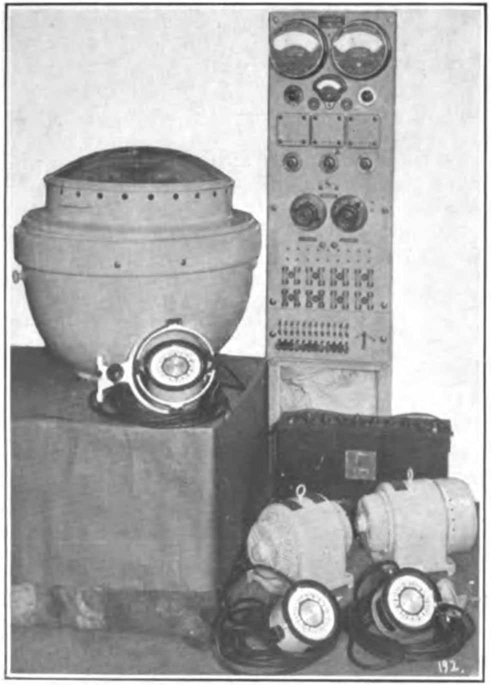
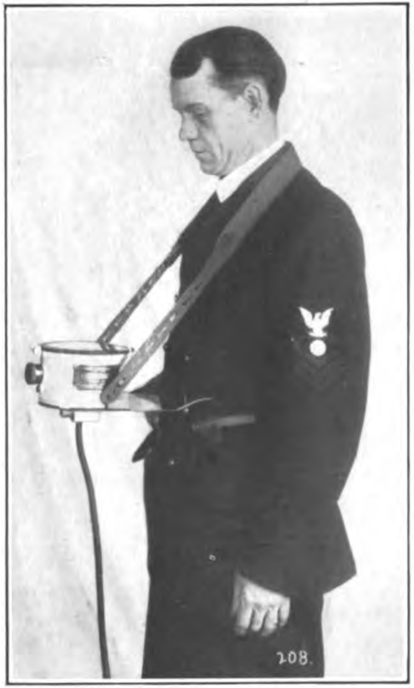
*H. C. Ford, *The Electrically Driven Gyroscope in Marine Work*, PROCEEDINGS A. I. E. E., June, 1914, p. 873.



[SPERRY]
FIG. 2—AMERICAN GYRO-COMPASS EQUIPMENT FOR SUBMARINE



[SPERRY]
FIG. 3—PORTABLE GYRO-COMPASS REPEATER

for from one to two hours, instead of immediately initiating a wide-angle swing from the meridian. Also, each acceleration or retardation pressure received by the compass from the ship is made to introduce a primary force exactly balancing the disturbing factor, which latter is very powerful and would otherwise swing the compass away from the meridian.

The master compass is never used upon the bridge or in any of the major helmsman or steering positions, but is down in a position of safety below the water line and protected deck of the vessel. The azimuth, however, is required at distant points and is supplied by repeater compasses electrically connected to the master, reproducing the azimuth to the accuracy of a very slight fraction of a degree and with practically zero time lag. The American equipment has a unique feature consisting of means for synchronizing all or any of the distant repeaters and bringing them into exact harmony with the master, rather than trying to do it by telephone at each individual repeater.

Another unique feature is an independent device connected with the master compass, giving extremely accurate indications as to whether or not the master compass is on the exact meridian. Coupled with this is an alarm system which gives automatic and vigorous notification if for any reason the master compass is off the meridian even a fraction of a degree.

We have heard a great deal about the performance of submarines in the present war. This performance is all the more interesting owing to this being the first opportunity that this new form of craft has had to exhibit its powers in actual warfare. In this connection a photograph of the entire gyro-compass equipment of one such a submarine might be of interest. Fig. 2 reproduces a photograph of the equipment of the English submarine *E*-9, which is reported to have performed some very startling feats near Cuxhaven at a considerable distance from its base, to which base the submarine again safely returned after, it is reported, having inflicted considerable damage on the enemy. The illustration shows the equipment which had been installed some six days prior to this performance. One of the repeater compasses of this equipment is provided with a long flexible cable and is portable (see Fig. 3), being capable of use in various parts of the ship, especially at the discharge valve of the torpedoes. The great precision with which the exact gyro azimuth of all periscopic observations may now be determined and also the high degree of precision with which the ship may thereafter be directed, gives assurance of accuracy of torpedo fire never heretofore attained, and probably unattainable by any other means.

I wish to express my great appreciation of Mr. Hornor's paper, which has gone into so many interesting details of these great ships which America is certainly proud of having built for our American neighbors.

H. L. Hibbard: After Mr. Sperry's gyroscopic oscillations, a discussion on some of the other points will perhaps seem rather commonplace, but I should like to make a few remarks on some of the things which Mr. Hornor outlined.

On the voltage question, there is, of course, a gain in the size of conductors and an appreciable gain in the size of controlling apparatus, especially on large auxiliaries, so that, aside from the slight objection, perhaps, to the use of as high voltage as this on the ship, the advantage seems to be on the side of the higher voltage.

As to the question of the banishment of the slate, it seems to me that has been a very good move, because all of us had considerable trouble with slate from breakage. When the company with which I am associated went to the Navy Department a few years ago and asked permission to supply asbestos switchboard panels, etc., on battleships, they gave consent very reluctantly, at our risk entirely. They now specify the asbestos material, which shows quite a change in opinion.

As regards electric steering gear, the chief advantages inherent in this type of apparatus were outlined pretty fully in my paper* presented at the May meeting in New York, it is not necessary to go into that further. I should like to ask Mr. Day if I correctly understood him to say that the decision as to the use of the contactor system on these ships was based on the ground of horse power only. Did that decide the matter?

Mr. Hornor brought up the question of whether or not it is of any real advantage to electrify the anchor windlass, and said that the principal advantage is in doing away with the steam pipes. That probably is the greatest advantage, doing away with the condensation of steam in those pipes and the weight of the piping, and also there is some saving in weight of the auxiliary itself. Further an electric motor is a better machine than a steam engine, and you can put in more power in the same space than you can with a steam engine. The steam engine has to be designed for maximum torque, and sufficient strength to develop that torque, while in the motor you have an overload capacity available that does not compare with the condition in the steam engine. Mr. Hornor said that the anchor windlass on the *Moreno* had one-half the horse power of the steam engine equipment. That is probably a misunderstanding. I should like to ask him what is probably the horsepower of the steam engine equipment.

One of the speakers made a reference to a dynamic brake in Fig. 16, which I should like to correct. The brake in the figure is a motor disk brake, on which point Mr. Day will bear me out. I also assume there is a dynamic brake in the equipment also.

With Mr. Pierce, I think that Mr. Hornor's statement in his last paragraph ought not to go entirely unquestioned, to the

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***Electricity the Future Power for Steering Vessels*, PROCEEDINGS A.I.E.E., May, 1914, page 703.

effect that the installation of a number of the auxiliaries in a new departure from American practise, particularly in the United States navy. As Mr. Pierce has said, on the Russian battleship constructed in Philadelphia before the *Moreno* was projected, most of these auxiliaries were installed. Also, the United States Navy at the time that this battleship was first started certainly had under test electric steering gears and had under consideration electric anchor windlasses, and long before the *Moreno* was constructed our navy had installations of both.

B. B. Bierer: There are a few things that I understood Mr. Pierce to say that have made me wish to make a few suggestions to those who are interested in the subject. One was the statement that there is no more use for two dynamo rooms on board a ship than there is for two engine rooms. That is correct, possibly, but I think there are, as a rule, two engine rooms on battleships, and sometimes three. We have tried the one dynamo room proposition and we have gone to two dynamo rooms or possibly an additional room for a Diesel engine above water for wireless, in case the dynamo rooms are submerged. We wish to take every precaution against placing the ship entirely out of commission. Of course the motive power might be placed out of commission with either one or two engine rooms, but that would still leave fighting power, provided we had a dynamo room in commission, as that is entirely electrically controlled—that is, lighting and fighting power and the wireless—and it would be a pretty dangerous proposition, even with the motive power out of commission, for someone else of at least smaller fighting power to come too near. In addition to the use of the wireless and power—which is electrical power—the fighting power of the ship—of course you can see very readily the advantages of having a number of means by which a ship cannot be put entirely out of commission.

I was very much interested in the remarks Mr. Pierce made in reference to the question of conduit or armored cable, because I have been associated with the use of conduit for a great many years, and the advantages that were claimed in the adoption of conduit have not been secured in the Navy, although we stuck to it for many years. One is water-tightness. That was impossible. The conduit installation was supposed to be water-tight, both in itself and where it passed through water-tight bulkheads, but in collisions that have occurred, when the compartment in collision was shut off and pumped out to put a patch on, water simply poured into the compartment and it was found it came through the conduit—simply had leaked in in streams. Now in addition to this leaking in in streams, when the decks are washed down and various things of that kind done, moisture gets into the conduit. It accumulates a mass of muck and corruption there at the end of a few years, everywhere the moisture gets in, and it is almost impossible to keep it out anywhere, any time or any place. That breaks down the insulation and one pretty soon finds so many grounds in the electrical installation of the ship, that were the ship to be used as a fighting machine and require all her electrical power, she would be absolutely unable to come up to the requirements.

Armored cable absolutely does away with grounds in the cable itself. Of course, there may be grounds in the junction boxes, connection boxes, and fixtures, but as far as the cable is concerned, unless that is pierced there are no grounds possible. The lead around the fibre insulation of the wire itself makes a perfectly water-tight seal. Then the mechanical protection—the wire braid—is very strong. You can bend that. You can put the end of the cable in a vise and bend it back and forth " until the cows come home," as they say, and it is still as good as ever, and the lead itself will break before the wire braid will.

Now as to the question of induction. We formerly used a great deal of what we call open work wiring instead of the conduit, to lessen weight and lessen this mass of pipes running around and underneath the beams—dust collectors and vermin collectors and having a most unsightly appearance. The question of induction, and wireless and other electric currents from one cable to another, was such that a short time—I don't mean to say a short space of time necessarily, but a short time in the life of a battleship—two or three years— will put the electrical installation out of commission as far as grounds are concerned. It had to be all gone over again every year. Where there is any trouble in conduit installation, it means tearing out the whole thing and putting in new. These are points in the consideration of conduit and wiring that come up from experience and are absolutely necessary to consider.

We do not have that small kuhlo (concentric) wire in use in our service, but it looks very good to me. It is neat, though a little expensive, and it certainly would be extremely desirable from a naval viewpoint.

J. H. Linnard: The great difficulty with the application of electricity to the windlass engine is the fact that the normal condition of a windlass when it is being operated is to be stalled, and you never know when that is going to happen. It stops at the most unexpected times. Now the question is, if you get the armature of your motor working at a speed that gives very considerable inertia forces how are you going to deal with that when the unexpected jam occurs, as it practically always does occur, when the anchors are being weighed? I haven't heard how that matter has been dealt with in these recent electrical installations for windlass engines, so that I do not feel able to speak about the matter.

I am glad to hear Commander Bierer tell us that conduit has been abolished in the later ships of the Navy, because from the point of view of a naval constructor it was precisely those difficulties of the weight and lack of water-tightness of conduit that always caused us to be on our knees to the Electrical Department to abolish it, but at that time they saw so many advantages in the use of conduit that they were unwilling to do so.

W. F. Cochrane: I appreciate the opportunity to join in the discussion of this paper, remarkable for its completeness, before this society that has done more to enlarge the field of electricity than any other organization in this or any other country. In fact, I think I may say that a great deal of the electrical supremacy of the American manufacturer is due to this Institute through its meetings and its frank and open criticisms.

Any criticism I may make of the paper that has just been read will be from the battle point of view and from the point of experience in the practical handling of electrical installations on board ship, and not from the standpoint of an expert electrician, as my electrical knowledge is limited to the practical handling of electrical installations on board ship.

The keynote of any installation for a battleship should be simplicity. If possible, only one voltage should be used on the entire ship for all purposes. The number of feeders should be reduced to a minimum and all efforts should be turned towards the one great objective of making the installation as simple as possible. The character of electricians available makes this element of simplicity imperative. The United States Navy has been rightly named " a great educational institution." The electricians that we have in the navy are men who enlist and have a small amount of experience and knowledge in electricity. These men are then sent to an electrical school where they receive instruction in the various appliances used on board ship. The period of time occupied by this is about one year; the man is then sent to some ship in an inferior position as an electrician. From this you can easily see how important the item of simplicity becomes in the design of the electrical installation of a battleship.

In the installation just described, I do not consider that simplicity has been attained to the extent that it could have been. First, in the use of 230 volts, for which a saving is claimed, but which we may seriously doubt, due to the installation of transformers to enable the searchlight system to be operated at the most advantageous voltage. I am not in favor of the use of high voltages on board ship unless a great saving in either weight or cost, or a simplification of the systems, will result therefrom. One disadvantage is that the use of higher voltage leads to considerably great liability to insulation troubles.

The installation of great numbers of protective devices, in my opinion, serves no useful purpose. There should not be any necessity for a protective device such as a circuit breaker, except at the switchboard. The line itself should require no protection. A fuse at the particular piece of apparatus on the line, whether it be a motor, indicator or any electrical instrument, should be ample protection for this installation.

In the matter of lighting circuits, we have, in the installation described, two battle lighting circuits, one white and one blue. I personally am not in favor of more than one battle lighting circuit, although the blue light circuit has its advantage in the fact that blue lights can be used in the gun deck compartments and will show very little light outside, but there should not be any necessity for general lighting around the compartment of a broadside gun. In turrets and in enclosed places, white lights are used as they cannot be seen from the outside. The greatest protection a battleship can have against submarines and destroyers operating at night is absolute darkness. The blue light circuit may not give much light, but it will certainly be easier to discover a battleship with a blue light circuit lighted than one with absolutely no light showing.

In regard to the battle lighting and power circuits of a battleship, I am heartily in favor of the use of alkaline storage batteries for the battle service. I believe that this is the best solution of the many problems confronting the designer of an electrical installation on board a battleship, because the storage battery can be installed in the turret to operate everything in the turret, and then the only possible way to affect the power units of the turret would be to put the turret itself out of commission.

In regard to interior communications, battle lighting, it is much better if operated by a storage battery which can be placed in such a position that before it is injured or any of the leads are injured, the ship itself will be practically destroyed insofar as she is valuable as a fighting unit. We may also say that an installation of this kind will save considerable space and some weight, as it will do away with the requirement of two dynamo rooms and it will be possible to place the dynamo room as an auxiliary to the engine room, or combine the two into one power plant, in case electric propulsion is adopted for battleships, as most of us believe it will be in the near future. It will combine the dynamo room and engine room in one locality that can be protected to such an extent that it will be practically impossible to injure the installation in any way.

The design of interior and exterior means of communication on a battleship is subject to practically constant change, and it is believed that these systems will be radically changed in the near future, with the advent of an invention to indicate automatically, in any part of the vessel, the color of smoke emitted from the stack, and with the application of the principles involved in this invention to general methods of interior communication in time of battle.

To sum up, the electrical equipment of the Argentine battleship *Moreno* is the most complete that I have ever seen, although I doubt the battle usefulness of a great many features that have been installed on board. I think it would be far more creditable if the designer had been able to say, " we have an installation that will produce the same results as the installation that was placed in the last battleship built, and we have only used half the miles of wire and half the fixtures and we only have half the number of protective devices and half the number of automatic starters and auxiliary instruments."

Clyde S. McDowell: Mr. Hornor described a method of telling the trueness of the searchlight mirror which is known as the "screen test;" it is done by photographing a reflected image of parallel wires or lines. However, this only shows the trueness of the grinding, and is not an indication of whether or not the mirror is parabolic. In addition to testing for trueness of grinding the mirrors should be tested for over-all efficiency. This can be done by taking a mirror and placing at the focus a concentrated-filament tungsten lamp or other source of light, and, at a distance far enough away so that the light varies inversely as the square of the distance, measuring by photometer across the beam in both directions the actual light received on the distant screen. In this method the source of light is known and always the same, and a true indication of the value of the mirror is obtained. It has been found by tests that one mirror which showed by the screen test to be perfectly true in its grinding, put up against another mirror which showed marked irregularities in grinding, did not show as good results in actual illumination, due undoubtedly to the structure of the glass, the thickness of the glass, or the color of the glass.

There was a question brought up as to the 220- and 110-volt systems on board ship for lighting. We have made numerous tests on vibrating platforms and lamps in both horizontal and vertical position, both 220- and 110-volt lamps—these platforms vibrating at the regular period of vibration of a ship—and in the sizes of higher wattage we find that the 220-volt lamps have as long life as the 110-volt lamps. That test is made with the lights on half the time and off half the time, so that the regular service conditions are obtained.

On the question of using a balancer set for searchlights on 220 volts, that is probably a good engineering way to cover it, but on some of our larger ships we are using 220 volts and have a balancer set to take the unbalanced lighting load large enough to take in addition the unbalanced load of four searchlights, which would be putting the searchlights on the lighting circuit.

On the question of doing away with conduit, one of the reasons why conduit has proved unsuccessful on board ship, especially in the fire rooms and engine rooms, has been the condensation in the conduit, irrespective of whether it was water-tight or not. The great changes in temperature that take place, cause the conduit to fill up with water.

Maxwell W. Day: A remark was made about the desirability of having the dynamo plant independent of the propelling machinery. This has just been illustrated in a recent naval battle, where the steam pipe of one of the German destroyers was shot in two, and the boat was seen to be enveloped in a cloud of steam, but frequent puffs of the gun were seen through it. Of course this was not an electrically operated gun, being only $3\frac{1}{2}$ inches, but it showed that the battery could be continued in action after the propelling machinery is out of order. It seems to me that one of the best ways to promote the independence of the dynamo plant is to bring into more extensive use oil-engine driven sets.

Naval Constructor Linnard spoke of the way of taking care of the anchor windlass in weighing the anchor, where the engine simply would slow down and stop. An ordinary control equipment of electric motors would naturally blow the circuit breaker. As mentioned in Mr. Hornor's paper, a step-back relay is provided, which will open some of the secondary connections of the accelerating contactors, and reinsert a certain amount of resistance in the armature circuit. This will allow the armature to receive about $1\frac{1}{4}$ times full-load current, or, of course, it can be adjusted for any other desired value. This was tested on the *Rivadavia* by setting the brake on the wildcat and screwing it down until it became sufficient to trip this step-back relay, when the motor stopped, and the current amounted to about 25 per cent overload.

Mr. Hibbard asked if we determined our recommendation for contactors solely on the horse power. It is primarily on current capacity, which would be also according to horse power, assuming voltage unchanged, and we have felt that in very large sizes frequent operation of the contactors successfully is quite a serious problem, and therefore we recommend the variable-voltage system for large units; but with only 150 h.p., and where 220 volts is used, as here, it brings it within the class of moderate-sized equipments.

Mention has been made of the disk brake on the steering gear motor, shown in Fig. 16. This brake is quite small, because we depend principally on the dynamic brake itself to stop the armature, or begin the stopping of it. The disk brake, which is a little slower in action, finishes the work, and holds the armature in a state of rest.

In regard to the material for switchboard and control panels, what is used for this purpose is ebony asbestos wood, called by some, asbestos lumber impregnated. It takes a fine polish, has very much the appearance of slate, and is preferable, I think, to what ordinarily goes by the name of asbestos lumber.

L. C. Porter: The chief difficulty in making 220-volt tungsten lamps is with the arcing. Where the leading-in wires come out of the stem, the current is apt to jump across. Considerable improvement has been made in this respect since the first lamps were put out, but at present the 220-volt lamps are not so free from arcs as the 110-volt, though the percentage of arcs is relatively small. Another difficulty encountered with the 220-volt lamp is what we call " locking " of the filaments. This consists of the filaments jarring together and short-circuiting a section, thus considerably shortening the life of the lamp.

The efficiency of the 220-volt lamp is also somewhat lower than that of the corresponding 110-volt lamp. For example, the 25-watt 110-volt lamp operates at 1.05 watts per candle; while the 25-watt 220-volt lamp operates at 1.2 watts per candle.

There are two types of filament construction used in the 220-volt lamps. In the regular pear-shaped bulb, with which you are all familiar, we use simply a straight wire filament. That filament is shaped on a form before it is placed in the lamp. It is also mounted on flexible anchors, which make the lamp mechanically just as strong as the 110-volt lamp. In the round bulb, and in the tubular bulb, in order to get the filament in the small bulb, we have to wind the filament into a helix and then mount it, which again lowers the efficiency of the lamp by cooling the filament at the anchors. In these lamps 1.06 watts per candle is the lowest specific consumption that we are able to obtain. Life tests on the 220-volt lamps of 25-, 40- or 60-watt sizes, under laboratory conditions, have shown that we obtain 2000 hours' life out of the straight filament and from 1200 to 1800 out of the coiled filament.

The tests which we have made on the lamps at the laboratory consist of vibration tests and bumper tests. The bumper test is made in this manner: We have an inclined board, at the end of which a lamp is hung on a piece of lamp cord. The board is graduated in inches and a round ball, weighing 110 grams, is rolled down this board, which has an elevation of 11½ deg. The ball is allowed to bump against the lamps, both cold and burning. Of course, lamps when burning are not quite so brittle as when cold, because the filament is softer when it is hot. Often with the lamps burning we can roll this ball from 40 to 60 in. against the lamp before the filament breaks, and that is just as far as we are able to roll it with the 110-volt lamps. In other words, the filament is mechanically as strong as the 110-volt lamp filament.

The vibration test is made upon a wheel with arms on it (similar to the spokes of a wheel), and the lamps are mounted at the ends of the arms. There is a series of cogs over which these arms pass. This wheel is revolved over the cogs at various speeds, with a little spring under each arm to pull it down, giving it a very severe vibration; in fact, we can get almost any vibration that we want. On that wheel I have seen as severe a vibration as is obtained on battleships under operating conditions. I have been aboard some of the ships during target practise, full-power run and a few other severe trials, and feel that in this test we give the lamps just as severe treatment as they obtain on the ships in actual service. However as I stated before, the trouble is not mechanical breakage, but locking of the filaments, which shortens the life.

It seems to me, therefore, that if there is a decided call for the 220-volt lamps, there need be no hesitation in installing them on the ships. Of course, it is a harder lamp to make, is more expensive, and is not made in such large quantities as the 110-volt lamps. For these reasons, from the lamp manufacturer's standpoint, we should prefer to furnish the 110-volt lamp, because it is a lamp with which we have had a great deal of experience. We have not had the 220-volt lamps under service conditions in any great numbers, and before being absolutely sure that they will be satisfactory, the most I can say is that we would suggest that, if possible, the same arrangement be made as was made with the 110-volt lamps; namely, that about 2000 lamps be put on a ship and tested in service. This, it seems to me, is the only sure trial which will absolutely prove the merit of the 220-volt lamp.

H. A. Hornor: I should like to explain an evident misinterpretation of the last paragraph of my paper. The various applications therein referred to constitute departures from American practise at the time the contract for the *Moreno* was signed Many of these applications were in an experimental stage at that time, and during the five years of construction of the *Moreno* naturally these applications have become requirements. As an illustration of this, the United States battleships *Arkansas* and *Wyoming* were not equipped with electric bilge pumps, electric steering gear; and electric anchor windlass; whereas the United States battleships *Texas* and *New York* were equipped with electric steering and electric bilge pumps but not electric anchor windlass. The later United States battleships are to be equipped with all these outfits. I did not intend my remarks to convey the impression that I was comparing previous foreign war vessels built in this country.

The horse power of the electric anchor windlass on the *Moreno* is a little less than ⅓ the horse power required of the steam equipment. It is to be noted that one anchor was raised in about 60 fathoms of water by this equipment using about 35 horse power after the anchor had " broken away."

I believe that there are many advantages in the use of 230 volts for such installations. I have heard it stated that some nations were considering the advisability of increasing the voltage to 500. If proper insulation is provided and all questions of detail carefully looked after, I see no reason why 230 volts should give any more trouble than the present 125-volt system. In this connection I was glad to hear the remarks on the comparative merits of the 220-volt tungsten lamp. On the ground of simplicity of installation, the use of this voltage would be preferable to the complications that would ensue from a system of double voltages. In view of the fact that the power load is now by far the greatest in point of importance it would seem preferable to design the installation so as to satisfy this demand first. The searchlights could very well be taken care of by rotary balancer sets in order to do away with the difficulties involved in large permanent rheostats. Such apparatus when tested on the *Moreno* gave unqualified satisfaction.

C

A. I. E. E. ANNUAL MEETING, MAY 18, 1915
Subject: Telephony. See page 107, Sec. I

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OF THE
American Institute
OF
Electrical Engineers

Volume XXXIV
Number 5

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OF THE

American Institute

OF

Electrical Engineers.

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GEORGE R. METCALFE, Editor

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Vol. XXXIV **May, 1915** No. 5

Annual Meeting of the A.I.E.E. New York, May 18, 1915

The 309th meeting of the American Institute of Electrical Engineers will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on Tuesday, May 18, at 8:15 p.m. This is the regular annual business meeting of the Institute, at which the Board of Directors will present its report for the fiscal year ending April 30, 1915. Copies of the report will be distributed and will include a detailed statement of the financial status of the Institute and a summary of the work accomplished by the standing and special committees during the year. The Committee of Tellers will present its report of the result of the election of officers for the coming administrative year.

Following the business meeting will be the presentation of the Edison Medal to Dr. Alexander Graham Bell. The presentation address will be made by Mr. John J. Carty, chief engineer of the American Telephone and Telegraph Company.

An address will then be given on "How Bell Invented the Telephone," by Mr. Thomas A. Watson, who was associated with Dr. Bell in the early development of the telephone. Members of the New York Telephone Society are invited to attend this meeting, and as the subject is one of general interest, ladies will be cordially welcome.

A. I. E. E. Annual Convention

The Convention Committee appointed by President Lincoln to arrange the details of the Annual Convention at Deer Park has been active during the past month, and as the result of its activities the Deer Park Convention promises to be a most enjoyable one in every respect. The technical and entertainment programs have been nicely balanced in order that the convention will prove both profitable and enjoyable to all who attend.

Deer Park, located on the crest of the Alleghanies on the main line of the Baltimore and Ohio, has been well known as a summer resort for a half century. Its climate in the summer is ideal, being cool enough for blankets every night. The hotel is an old-fashioned rambling structure, with adjacent annexes and wide porches, but everything is comfortable and the service is excellent. The building is situated in the midst of a large well kept lawn, backed up by virgin forests, with golf links, bowling alleys, tennis courts, baseball grounds, swimming pools, beautiful walks and drives, all at the free service of our members and guests.

The Baltimore and Ohio Railroad will provide fine train service from all important centers, as will be seen from the train schedule published below.

The hotel is capable of accommodating 300 people comfortably, and any reasonable number in excess can be accommodated in some of the big cottages grouped about the hotel. In addition to this, Mountain Lake Park and Oakland are near enough to be utilized as

Trains 55, 1 and 3 have through Pullman cars from New York, Philadelphia, Baltimore and Was ington to Deer Park Hotel.

Train No. 11 has through Pullman car from Baltimore to Deer Park Hotel, but connects at Wa ington with the "Royal Limited" from New York and Philadelphia.

Trains Nos. 2, and 12 have through sleeping cars from St. Louis and Cincinnati to Deer Park Ho and Train No. 2 has through sleeping car from Louisville to Deer Park Hotel. Train No. 4 has thro sleeping cars from Cincinnati to Deer Park Hotel.

Trains Nos. 8, 6, 10 and 16 from Chicago and Pittsburgh make connections at Cumberland w trains to Deer Park Hotel as per schedule, change of cars at Cumberland being necessary.

Train No. 2 has through sleeping car from Columbus and Wheeling to Deer Park Hotel.

	RAILROAD FARES		PULLMAN FARES	
	One-Way	Round-trip	Lower-Berth	Drawing Ro
New York	$11.09	$17.00	$2.50	$9.00
Philadelphia	8.84	13.00	2.25	8.00
Baltimore	6.44	9.00	1.50	6.00
Washington	6.01	8.00	1.50	6.00
Pittsburgh	*5.43	7.95	2.00	7.00
Pittsburgh	†5.70			
Cincinnati	9.83	12.75	2.00	7.00
St. Louis	19.90	27.15	4.00	14.00
Chicago	14.69	22.80	3.50	13.00
Buffalo	10.12	17.35	No through Pullman servi	
Cleveland	7.29	11.70	" " " "	
Detroit	11.07	17.55	" " " "	

*—Via Cumberland.

†—Via Connellsville or Wheeling.

NOTE: From Atlanta, the Southern Railway round trip rate to Deer Park is $30.25. Southern Railway train No. 38 leaves Atlanta 12:05 p. m., arriving at Washington 7:45 a. m.; train No. 30 leaves Atlanta 2:25 p. m., arriving at Washington 10:40 a. m. See table above for connections from Washington to Deer Park.

Panama-Pacific Convention

Arrangements for the Panama-Pacific Convention which were outlined in the April issue of the PROCEEDINGS are progressing rapidly at the hands of the general convention committee. The subdivision of the work of this committee has been decided upon as follows:

W. W. Briggs, hotels and hotel arrangements.

A. H. Babcock and A. M. Hunt, papers.

H. A. Lardner, meetings and halls.

J. T. Whittlesey and C. J. Wilson, entertainment.

A. G. Jones, secretary.

C. L. Cory, publicity.

A general circular was mailed under date of March 22, by the Joint Committee in Charge of Transportation, to all members of the A. I. E. E. and the other societies concerned, giving information on transportation, hotel rates, etc., in connection with the International Engineering Congress, and the conventions of the A. S. C. E., A. I. M. E., A. S. M. E., and A. I. E. E.

The matters of entertainment and tours in connection with the Panama-Pacific Convention of the A. I. E. E. and the International Engineering Congress have been taken up by a committee representing the Congress and all of the engineering societies concerned, and a schedule is being prepared setting forth a number of trips of interest that can be made by members attending these meetings. Further reference to these trips will be made in future issues of the PROCEEDINGS.

Section Delegates to Annual Convention

AMENDMENT TO BY-LAWS

At the conference of Section Delegates during the Detr[illegible] last June, a resolution was passed requesting the Board of Directors to consider a revision of the Constitution so as to incorporate therei[illegible] functions and duties of the [illegible] Delegates attending annual [illegible]tions.

This action was brou[illegible]

tention of the Board of Directors on August 11, 1914, and was referred to the Sections Committee, with the suggestion that on account of the long process and time required to conform to the legal procedure of amending the Constitution, consideration be given to the possibility of carrying out the recommendation of the Delegates by amending the By-laws.

Chairman Hornor of the Sections Committee communicated with the chairmen of all Sections and the other members of his committee on this subject, under date of November 9, 1914, inviting suggestions on a proposed by-law to cover the matter.

Based upon the comments and suggestions received by Mr. Hornor, a draft of a proposed amendment to the by-laws was prepared, embodying suggestions received, which related to the duties of Section Delegates and which were in accordance with the Constitution of the Institute.

This by-law was adopted by the Board of Directors of the Institute at its meeting held April 9, and reads as follows:

"Sec. 60-A. SECTION DELEGATES. The principal functions and duties of the Section Delegates attending the annual convention, as provided in Sec. 70 of the Constitution, shall be as follows:

"(a) To attend such meetings of the Sections Committee as may be held during the convention.

"(b) To exchange views and experience in connection with Section activities and management and to make recommendations of an advisory nature upon such matters to the Board of Directors. (Const. Sec. 54).

"(c) To exchange and discuss ideas regarding subjects for inclusion in technical programs of future Section meetings.

"(d) To advise the Chairman of the Sections Committee at least sixty days in advance of the convention of questions of interest to the Institute Sections which, in their opinion, should be discussed by the Delegates at the meetings of the Sections Committee during the convention. The Chairman of the Sections Committee shall appoint a sub-committee of three, who with the chairman, ex-officio, shall prepare, in advance of the convention, a program of such questions for discussion.

"(e) Past-chairmen or chairmen-elect of Sections, if in attendance at the convention, will be privileged to attend all meetings of the Sections Committee, but each Section will be entitled to one vote only, which shall be cast by the Chairman of the Section or other official delegate."

United Engineering Society Condensed Financial Statement for the Year 1914

The statement of assets and liabilities presented herewith, shows the financial condition of the Society on December 31, 1914, at which time the Society had in addition to the value of its real estate, the following funds:

In the Depreciation and Renewal Fund (to provide against the gradual disappearance of the Society's assets)	$51,441.39
In the General Reserve Fund	10,000.00
and a Surplus of	9,243.17

this surplus being made up of—

Cash and current accts.	7554.42
Surplus invested in library books	1688.75

The amount expended for furniture and fixtures during 1914 was $671.62. In accordance with a resolution of the Trustees, the expenditures for furniture and fixtures are no longer carried as assets.

The total revenue from all sources was $59,054.77.

The total of expenditures was $50,715.40, a difference of $8339.37, which sum is not sufficient to meet the annual requirement of $10,000.00 which should be placed in the Depreciation and Renewal Fund.

The principal of the mortgage held by Andrew Carnegie, Esquire, on the land, amounting originally to $540,000.00, has been reduced by payments during the year of $29,000.00 by the American Institute of Mining Engineers. On December 31, 1914, the balances due from the Founder Societies were as follows:

American Institute of Electrical Engineers	$54,000.00
American Institute of Mining Engineers	5,000.00

This last mentioned amount was paid in January, 1915, so that the American Institute of Mining Engineers and the American Society of Mechanical Engineers have paid the full amount of their land indebtedness.

The Trustees, by appropriate resolutions, have established a General Reserve Fund of $10,000.00 which is not assigned to any specific purpose, but is to meet fluctuations in income and disbursements; also a Depreciation and Renewal Fund to provide against the gradual disappearance of the Society's assets. The sum of $50,000.00 has been placed in this Fund and, by resolution, the sum of $10,000.00 per annum is to be added to it, as well as all interest earned by the fund. It amounted c December 31, 1914, to $51,441.39.

Of the above-mentioned funds, tl sum of $39,863.75 had been invested c December 31 in interest-bearing s curities. A further investment of ap proximately $18,000.00 was made i January, 1915.

The Trustees have appointed a trus company to be the custodian of th Society's invested securities.

An expenditure of $5,814.00 was mad during the year for additions and altera tions on the sixth floor of the buildin The additional space thus acquired i used largely for storage rooms.

On December 31, 1914, there was n unoccupied office space in the building. Seventeen associate societies now have their headquarters in the building.

The record of the number of times the rooms were used during 1914 for meetings or lectures—not for office occupancy—is as follows:

Meeting Room	Number of times occupied		
	1913	1914	Change
Auditorium 3rd and 4th floors	69	76	7 more
No. 1 Assembly Room 5th floor	56	58	2 "
" 2 " " 5th "	129	94	35 less
" 3 " " 5th "	101	46	55 "
" 5 Lecture " 6th "	10	0	10 "
" 8 " " 6th "	20	0	20 "
Assembly Room 1201 12th "	18	53	35 more
Committee room (off Foyer) 1st "	10	18	8 "
Total	413	345	68 less

During the year 1914 there were added to the Library of the three Founder Societies and the United Engineering Society 3,616 volumes and pamphlets, of which 1,142 volumes and pamphlets were purchased at a cost of $3,153.20. The total number of books and pamphlets at the end of the year was 57,861.

The attendance during the year was 13,512 as compared with 11,091 during 1913, an increase of 2,421.

There were 198 searches made during the year. Correspondence has come from all over the world, [illegible] tions are of great variety. [illegible] dred photographic repro [illegible] been made and sent ou [illegible] 1200 reference questio [illegible] answered at the desk.

The Library receives [illegible] periodicals which are av [illegible] indexes for research pur [illegible]

Respectfully [illegible]

JOSEPH [illegible]

Treasurer.

UNITED ENGINEERING SOCIETY

STATEMENT OF ASSETS AND LIABILITIES

DECEMBER 31, 1914.

ASSETS:

Original cost of land	$540,000.00	
Preliminary expenses	24,000.00	
		$564,000.00
Expended on building—Carnegie gift	1,050,000.00	
" " " —Founders contributions	10,039.85	
" " —from U. E. S. income	23,131.31	
		1,083,171.16
TOTAL cost of real estate to date		$1,647,171.16
Unexpired insurance		3,333.10
Accounts receivable		5,032.30
Invested in library books		1,688.75
Bond investments at cost		39,863.75
Cash		24,546.22
		$1,721,635.28

LIABILITIES:

Equity of Founders in property	$1,624,039.85	
Less indebtedness of Founders	59,000.00	
	$1,565,039.85	
Investment of U. E. S. in building from income	23,131.31	
		$1,588,171.16
Land indebtedness		59,000.00
TOTAL		$1,647,171.16
Due to the Depreciation and Renewal Fund		51,441.39
Due the General Reserve Fund		10,000.00
Accounts payable		3,779.56
TOTAL		$1,712,392.11
Surplus—cash and current accounts	$7554.42	
Surplus—invested in library books	1688.75	
Total surplus		9,243.17
		$1,721,635.28

Correct:

CHARLES F. RAND
JESSE M. SMITH
H. H. BARNES, JR.
Finance Committee.

Revision of Constitution—Notice to Membership

At the meeting of the Board of Directors of the Institute held April 9, 1915, the following resolutions were adopted:

"*Resolved*, that it is the sense of this Board that a committee to consider revision of the Institute Constitution should be appointed early in the next administrative year, which begins August 1, 1915, and, further

"*Resolved*, that the attention of the Institute membership be called, by publication of these resolutions in the monthly Institute PROCEEDINGS, to the probability of action next year toward a revision of the Institute Constitution, and that the membership be hereby requested to submit, through the Secretary, suggestions for amendments to the present Constitution of the Institute, so that these suggestions may receive prompt consideration by the Revision Committee, when appointed."

A copy of the present Constitution may be obtained upon application to the Secretary.

A. I. E. E. Specification for Testing High-Tension Porcelain Line Insulators

During the last three years the subject of the inspection and test of high-tension porcelain line insulators has been under discussion by the A. I. E. E. The need of more uniformity in the commercial testing practise on such insulators has long been manifest and the very erratic behavior of insulators on several of our important lines has indicated a need for more searching tests. As a result of the consideration of these questions by various Institute committees during this period a specification has been drawn up by the present Transmission Committee which is intended to serve as a model or skeleton specification covering the inspection and testing of high-tension line insulators.

With the authorization of the Board of Directors this specification has been approved and recommended by the Transmission Committee and copies are now available on application to the Secretary of the A. I. E. E.

The Specification, which is entitled, "Provisional Specification covering Inspection and Test of High-Tension Line Insulators of Porcelain for Over 25,000 Volts" is printed elsewhere in this issue of the PROCEEDINGS.

This specification does not include specific instructions covering the very important subject of impact or high-frequency testing, as this subject is not yet considered sufficiently well standardized. It is expected, however, that the specification will be added to and amended from time to time to keep it closely in touch with the best practise.

Appointments to International Jury of Awards, Panama-Pacific Exposition

Announcement has been made of the appointment by President Moore of the Panama-Pacific Exposition, San Francisco, of the following men to serve on the electrical division of the International Jury of Awards: Messrs. Allen H. Babcock and Guy L. Bayley of San Francisco, George A. Damon of Los Angeles and Throop College of Technology, Pasadena, Arthur H. Halloran of San Francisco, Dr. Carl Hering of Philadelphia, Professor Cyril M. Jansky of the University of Wisconsin, Professor Vladimir Karapetoff of Cornell University, William H. Onken, Jr., of New York, Cecil P. Poole of Atlanta. Professor Harris J. Ryan of Leland Stanford, Jr., University, Honorary Vice-President of the A. I. E. E., and Dr. Frank A. Wolff of Washington, D, C. All of these men are members of the Institute. This is not a complete list of the electrical division of the Jury of Awards, as several appointments are still in doubt.

Cleveland Meeting of the Institute, March 18-19, 1915

The 306th meeting of the Institute was held March 18 and 19, 1915, in Cleveland, Ohio, at the Hollenden Hotel, under the auspices of the Industrial Power Committee and the Cleveland Section. The registration of attendance reached 309, of which number 27 were from outside of Ohio.

The meeting was called to order promptly at 9:30 on Thursday morning, March 18, by Mr. Howard Dingle, chairman of the Cleveland Section. An address of welcome to the members and their guests was made by Dr Cooley, representing Mayor Baker, and then President P. M. Lincoln took the chair The first two papers on the program were presented at the morning session. During the remaining technica sessions the papers were presented and discussed in accordance with the program published in the March PROCEEDINGS

On Thursday noon a joint luncheon was held with the Electrical League of Cleveland, with 180 present. Mr. G E. Miller presided, and Mr. Samuel G McMeen, president of the Ohio Stat Telephone Company and of the Columbus Railway and Light Company made the principal address.

The afternoon was devoted to inspection tours to the National Electric Lamp Works of the General Electric Company, the Cleveland Electric Illuminating Company's Lake Shore station, and the Municipal Electric Lighting station. Mr. C. J. Pagano made the arrangements for these inspection trips.

The banquet was held on Thursday evening, in the assembly hall of the Hollenden Hotel Mr. H. J. Davies, secretary and treasurer of the Cleveland Railway, was toastmaster, and the other speakers were Chairman D. B. Rushmore of the Industrial Power Committee, Dr. Charles S. Howe, president of the Case School of Applied Science, whose subject was "Scientific Research," President P. M. Lincoln of the Institute, and Mr. Samuel G. McMeen. The success of the banquet was largely due to the efforts of Mr. C. S. Powell, chairman of the banquet committee, and Mr. Dingle, chairman of the Cleveland Section.

Friday was devoted to the presentation and discussion of the remaining four papers, in morning and afternoon sessions.

The large attendance at the meeting was in great measure the result of the efforts of Mr. Evan J. Edwards, chairman of the committee on Membership Acquaintance and Attendance, and Mr. H. L. Wallau of the Cleveland Electric Illuminating Company. Others who were active in the work of organizing the meeting were Professor H. B. Dates and Messrs. W. M. Skiff, L. P. Creeelius, R. E. Scovel, Maurice Converse, A. P. Lewis and E. H. Martindale. The Industrial Power Committee has three members in Cleveland—Messrs. A. C. Eastwood, J. C. Lincoln and E. H. Martindale.

Meeting of the A. I. E. E in New York, April 9, 1915

The 307th meeting of the Institute was held Friday, April 9, 1915, on the fifth floor of the Engineering Societies Building, beginning at 8:25 p.m.

President Paul M. Lincoln called the meeting to order, and said that as the paper of the evening had been contributed through the agency of the Electrophysics Committee, he would call on Dr. John B. Whitehead, the chairman of that committee, for an introductory address. Dr. Whitehead called attention to the fact that the Institute of Radio Engineers had been invited to participate in the meeting, and that many of the members of that society were present.

President Lincoln then called on Mr. L. F. Fuller to present his paper, *Continuous Waves in Long-Distance Radio Telegraphy.* Those who discussed the paper were Messrs. Alfred N. Goldsmith, J. Zenneck, Lee de Forest, A. J. Hepburn, E. F. W. Alexanderson, G. H. Clark, and L. H. Fuller.

After the close of the technical session, a smoker was held in the adjoining room.

Pittsburgh Meeting of the Institute, April 15-16, 1915

The 308th meeting of the Institute was held in Pittsburgh, at the Fort Pitt Hotel, on April 15 and 16, 1915, with a technical program of seven papers, presented under the auspices of the Industrial Power Committee in cooperation with the Pittsburgh Section. The total registration for this meeting was 216.

The meeting was opened 9:30 a.m. on Thursday, April 15, by Mr. J. W. Welsh, chairman of the Pittsburgh Section, and introductory addresses were made by Chairman D. B. Rushmore of the Industrial Power Committee and President P. M. Lincoln. The papers were presented in accordance with the program published in the April PROCEEDINGS.

On Thursday a joint luncheon was held with the Pittsburgh Jovians, at which 139 were present. An address was delivered by Morris Knowles of Pittsburgh on "The Civic Responsibilities of the Engineer."

Thursday evening 68 members and guests attended an informal dinner, at which addresses were made by President Lincoln and Dr. John A. Brashear, whose subject was "Reminiscences of Scientific Discoveries." At the close of Dr. Brashear's talk 55 of the visitors and local members attended the theater in a body. On Friday, 42 members participated in an Institute luncheon.

Directors' Meeting, New York, April 9, 1915

The regular monthly meeting of the Board of Directors of the Institute was held in New York on Friday, April 9, 1915, at 3:30 p.m.

There were present: President P. M. Lincoln, Pittsburgh, Pa.; Past-Presidents Ralph D. Mershon and C. O. Mailloux, New York; Vice-Presidents H. H. Barnes, Jr., and C. E. Scribner, New York, Farley Osgood, Newark, N. J.; Managers Comfort A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y., Frederick Bedell, Ithaca, N. Y., A. S. McAllister, New York, John H. Finney, Washington, D. C.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The Secretary announced the following additional committee appointments made by President Lincoln since the last meeting: Special Committee on Hazards from Lightning: Messrs. Elihu Thomson, Chairman, A. E. Kennelly, Secretary, Comfort A. Adams, Louis Bell, Dugald C. Jackson.

President Lincoln also appointed Mr. S. G. McMeen a member of the Edison Medal Committee to fill the unexpired term of Mr. H. Ward Leonard, deceased. This appointment was confirmed by the Board as required under the Edison Medal Committee's by-laws.

Mr. John W. Kirkland of Johannesburg, South Africa, was appointed Local Honorary Secretary for South Africa, for the term ending July 3 1916.

The action of the Finance Committe in approving monthly bills amountin to $8,868.73 was ratified.

Upon the recommendation of th Meetings and Papers Committee, a thority was granted to hold an Inst tute meeting at Philadelphia, Pa., o October 11, 1915, under the auspice of the Philadelphia Section; also a Institute meeting at St. Louis, Mo. under the auspices of the St. Loui Section. The exact date of this meeting is to be determined later.

Upon the recommendation of th Board of Examiners, the Board o Directors transferred three Associates to the grade of Member, elected six applicants as Members and 59 as Associates, and ordered the enrolment of 73 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

Past Section Meetings

Baltimore.—March 26, 1915. Physical Laboratory, Johns Hopkins University. Subject: Electric Railways. Paper: "Car Operation," by John F. Layng. Attendance 28.

Boston.—March 24, 1915, Engineers Club. Illustrated lecture by Dr. Saul Dushman on "The Electron Theory and its Applications." Attendance 85.

Chicago.—March 22, 1915. Paper: *The Flow of Energy*, by R. A. Philip. Joint meeting with Weste [illegible] of Engineers. Attendance [illegible]

Detroit-Ann Arbor.—Mar [illegible] Hotel Statler, Detroit. A [illegible] quet of Section. Address [illegible] P. Bird on "Relation of the [illegible] to the Electrical Professi [illegible] tendance 119.

March 26, 1915, Detroit E [illegible] Society Club Rooms. Pap [illegible] ciples of Steam Turbines," by J. E. Emswiler, illustrated. Attendance 42.

April 9, 1915, Detroit Engineering Society Club Rooms. Paper: "The Development of the Internal Combustion Engine, with Especial Reference to the Useful Recovery of Heat Losses." by J. B. Merriam, illustrated by lantern slides. Attendance 55.

Fort Wayne.—March 26, 1915, Commercial Club. Address by Mr. J. W. Anspach on "The Manufacture of the Mazda Lamp." Attendance 11.

Indianapolis-Lafayette. March 19, 1915, Indianapolis. Subject: Telephony. Paper: "What Happens on the Telephone," by J. L. Wayne. Attendance 50.

Ithaca.—February 27, 1915, Cascadilla Dining Hall. Annual Banquet of Section. Addresses by Dean E. L. Nichols, Professors Vladimir Karapetoff, J. R. Turner, C. A. Adams, Mr. H. A. Clarke, and President P. M. Lincoln. Piano recital by Prof. Karapetoff. Attendance 76.

March 12, 1915, Rockefeller Hall, Cornell University. Experimental lecture by Prof. Ernest G. Merritt on "Crystal Detectors in Wireless Telegraphy." Attendance 110.

March 26, 1915, Franklin Hall, Cornell University. Annual debate; subject—"Resolved, that the electrification of the Tehachapi Division of the Southern Pacific Railroad would not be justified on the basis of present traffic conditions." Messrs. A. M. Beebe and F. H. Wiley took the affirmative, and J. R. Fry and H. M. Sharp the negative. The judges decided in favor of the affirmative. Attendance 45.

Los Angeles. — March 16, 1915, Chamber of Commerce. Paper: "The Building of the Transcontinental Telephone Line," by Mr. Fullerton, illustrated by lantern slides and moving pictures. Attendance 60.

Lynn.—March 17, 1915, General Electric Works. Illustrated lecture by Dr. W. P. Davey on "X-Rays." Attendance 249.

Milwaukee.—February 24, 1915, Republican House. Paper: "Electrification of the Panama Canal," by Edward Schildhauer. Attendance 100.

March 10, 1915, Plankington House. Paper: "Some Notes on Electrical Excavating Machinery," by Walter Ferris. Attendance 100.

April 14, 1915, Plankington House. Paper: "Clean Water." by Allen Hazen. Meeting under auspices of local section of A. S. M. E. Attendance 200.

Panama.—February 28, 1915, Balboa Y. M. C. A. Paper: "Transmission System Substations, Including a Discussion of the Electrical Characteristics of the Equipment and Methods of Installation and Construction," by O. C. Atkinson and A. T. Sjoblom. Attendance 45.

March 28, 1915, Darien Radio Station. Addresses as follows— (1) "Some Features of the Operation of Darien Station and Its Function in the Navy Radio System," by R. S. Crenshaw; (2) "The Construction Work and Erection of the Radio Station," by Ira W. Dye; (3) "The Theory of the Radio Installation at Darien," by Lewis W. Austin. Attendance 56.

Philadelphia.—April 1, 1915, Franklin Institute. Paper: "Modern Theories of Magnetism," by George F. Stradling.

April 12, 1915, Engineers Club. Paper: "Turbine-Driven vs. Engine-Driven Units in Small Capacities," by J. S. Barstow. Joint meeting with local section A. S. M. E. Attendance 220.

Pittsfield.—March 11, 1915, Hotel Wendell. Paper: "The Leakage Reactance of Synchronous Alternators and Its Relation to Sudden Short Circuits," by C. A. Adams. Attendance 69.

April 1, 1915, Hotel Wendell. Paper: "Recent Research Work of the Electrical Division of the Bureau of Standards," by P. G. Agnew. Attendance 60.

Portland.—March 30, 1915. Lecture on "Safety First," illustrated by lantern slides and moving pictures.

Rochester.—March 26, 1915. Paper "Marginal Economies," by John C. Parker. Attendance 33.

San Francisco.—March 26, 1915, Engineers Club. Paper: "Electrochemical Possibilities on the Pacific Coast," by Romaine Myers. Attendance 37.

Schenectady.—March 30, 1915. Edison Club Hall. Paper: "Driving Ship Propellers," by W. L. R. Emmet. Joint meeting with eastern section N. E. L. A. Attendance 302.

April 6, 1915, Edison Club Hall. Paper: "Problems in Transformer Design," by G. Faccioli. Attendance 101.

Seattle.—March 17, 1915, Seattle Press Club. Address by Mr. W. L. Locke on "The Big Creek Power Development of the Pacific Light and Power Company," illustrated by lantern slides and moving pictures. Attendance 97.

Spokane.—March 19, 1915, Chamber of Commerce Building. Papers: "Diversity of Heating Load," by H. B. Peirce; and "Voltage Regulation on Lighting Circuits," by D. F. Henderson Attendance 35.

St. Louis.—April 15, 1915, Engineers Club. Paper: "Hydro-electric Development in the Pacific Northwest," by A. R. Fairchild. Attendance 34.

Toledo.—April 7, 1915, residence of George E. Kirk. Address by Mr. Little on "Engineering Progress of the Present Day, and the Tendency of the Future." Address by Mr. Kirk on "Italy," illustrated with colored views of places of interest. Attendance 20.

Urbana.—March 19, 1915, Electrical Laboratory. Paper: "Lightning and Lightning Protection," by Ellery B. Paine. Attendance 65.

Vancouver. — January 14, 1915. Metropolitan Building. Paper: "Inductive Disturbances as Affecting Telephone and Telegraph Lines," by H. W. Keifer. Attendance 18.

February 19, 1915, Metropolitan Building. Paper: "Transformers," by Mr. Paget. Attendance 13.

March 26, 1915. Metropolitan Building. Paper: "Electric Pumps for Sewerage Disposal," by D. P. Dunn. Attendance 10.

Washington.—March 18, 1915, Cosmos Club Hall. Address by Commander A. J. Hepburn. U. S. N., on "Experimental Radio Work from the Executive Point of View." Attendance 42.

Past Branch Meetings

Armour Institute.—March 18, 1915, Engineering Rooms. Papers: (1) "Automatic Railway Control" by G. A. Barrer; (2) "Concentric Wiring," by A. A. Oswald. Attendance 15.

Bucknell University.—April 9, 1915, Chemical Laboratory. Address by Mr. F. A. Neff on "The Growth of a Great Modern Utility." Attendance 16.

University of California.—February 17, 1915, Berkeley. Address by Mr. G. W. Cattell on "Three Types of Rectifiers: Mercury Arc, Magnetic and Electrolytic Type." Attendance 19.

March 3, 1915. Paper: "The Theory of the Repulsion Motor," by S. D. Browning. Demonstration of transformer winding machine, the invention of Frank Rieber. Attendance 23.

March 17, 1915. Paper: "Cable Feeder Tests Conducted on the Oakland Traction Company and Key Route Systems in Oakland and Berkeley," by H. F. Reid.

March 31, 1915. Paper "Electrical Equipment of the Latest Automobiles," by C. J. Erickson. Attendance 20.

University of Cincinnati.—March 25, 1915. Address by Mr. R. P. Kincheloe on "The Use of Lightning Arrester High-Tension Transmission Lines." tendance 44.

University of Colorado.—March 18, 1915. Boulder. Address by Mr. H. R. Whitehead on "Electrolytic Refining in the U. S. Mint, Denver." Attendance 30.

March 25, 1915, Engineering Building. Address by Mr. H. C. Bullock on

"Storage Battery Locomotives." Attendance 20.

Georgia School of Technology.—March 11, 1915, Chemistry Building. Paper: "Application of Electricity to Cotton Mills," by Park A. Dallas. Attendance 46.

April 2, 1915, Electrical Building. Paper: "Regulators and Feeder Regulation," by T. Fuller. Attendance 37.

University of Idaho.—March 3, 1915. Papers: (1) "Power Situation in Southern Idaho," by H. J. Adams; (2) "Public Utilities Commission in Idaho," by J. J. Gill. Attendance 20.

Kansas State Agricultural College.—January 11, 1915, Electrical Engineering Department Lecture Room. Paper: "Applications of Electricity on the Farm and Home," by H. E. Newhouse, illustrated with lantern slides. Attendance 20.

February 8, 1915, Lecture Room, Library. Papers: (1) *Theoretical Investigation of Electric Transmission Systems under Short-Circuit Conditions*, by I. W. Gross; (2) *Insulator Depreciation and Effect on Operation*, by A. O. Austin. Attendance 30.

March 15, 1915. Lectures on "The Edison Storage Battery" and "The Exide Standby Battery." Attendance 36.

University of Kansas.—March 16, 1915, Lawrence. Address by Mr. C. R. Dooly on "Methods of Westinghouse Company in Handling their Men." Attendance 30.

March 29, 1915. Illustrated address by Mr. W. A. Bucheim on "Experiences in the Canary Islands in Measuring ht by the Electrometer." Attendance 45.

University of Kentucky.—April 14, 1915, Mechanical Hall. Paper: "Protective Apparatus," by F. H. Nealis. Attendance 38.

Lafayette College.—February 18, 1915, Pardee Hall. Papers: (1) "Methods of Varying Speed in A-C. Motors; (2) "Electric Railway Coasting;" (3) "Electricity Direct from Coal;" (4) "Municipal Lighting System of Easton, Pa.;" (5) "Street Railway Electrolysis." Attendance 21.

March 11, 1915. Papers: (1) "Dielectric Strength of Air;" (2) "Outdoor vs. Indoor Substations;" (3) "The Place of Exhaust Steam Turbines in Power Plants;" (4) "Electric Railway Signaling." Attendance 21.

March 20, 1915. Election of officers as follows—president, R. Fox; vice-president, H. Woodward; secretary, I. Schlough. Attendance 19.

Lewis Institute.—February 15, 1915. Paper "Manufacture of Insulated Wire, by Henry A. Morss, illustrated by moving pictures. Attendance 300.

University of Michigan.—March 11, 1915, Engineering Building. Paper: "*Troubles Encountered in the Use of Carbon Brushes on D-C. Motors and Generators*," by E. H. Martindale. Attendance 34.

Montana State College.—March 19, 1915, History Lecture Room. Address by Mr. Hamilton Steel on "The Construction of the Dam and Power House at the Great Falls," illustrated with lantern slides. Attendance 28.

University of Nebraska.—March 3, 1915, Electrical Building. Addresses: (1) "Hydroelectric Plants in Nebraska," by O. E. Edison; (2) "Some Keys to Successful Engineering," by Prof. Hollister. Attendance 30.

April 7, 1915. Address by Mr. Frank Allen on "Electric Automobiles." Attendance 35.

North Carolina College of Agricultural and Mechanical Arts.—March 16, 1915, West Raleigh. Illustrated lecture on "Lightning Arresters, Meters, Circuit-Breakers, Oil Switches and Switchboards." Attendance 20.

March 23, 1915. Experiments demonstrating the principle of sending and receiving wireless messages. Attendance 20.

March 30, 1915. Paper: "Construction of City Electric Lines." Experiment on arc lights showing the source of light and the effect of putting metal in the carbons. Attendance 20.

April 6, 1915. Demonstration of constant-current transformer, using an arc light circuit. Attendance 15.

April 13, 1915. Address by R. Crowder on "Electric Starters for Automobiles." Attendance 21.

Ohio Northern University.—March 17, 1915, Hill Memorial. Papers: (1) "The Pennsylvania Electrification," by W. L. Riggin; (2) "Underground Wiring," by H. L. Frapwell. Attendance 22.

March 31, 1915. Papers: (1) "Transformer Testing," by R. E. Lowe; (2) "Current-Limiting Reactances and the Induction Regulator," by E. C. Vroman. Attendance 14.

Ohio State University.—April 9, 1915. Robinson Laboratory. Paper: "Wireless Telegraphy," by R. E. Brown. Attendance 26.

University of Oklahoma.—March 24, 1915, Engineering Building. Papers: (1) "Electrolytic Iron;" (2) "Electro-Culture;" (3) "Characteristics of Motors;" (4) "Store Keeping;" (5) "Current Events." Attendance 20.

Oregon Agricultural College.—March 5, 1915, Corvallis. Address by Mr. O. B. Coldwell on "The Field of Electrical Engineering." Attendance 39.

University of Pittsburgh.—March 10, 1915, Thaw Hall. Paper: "Some Features of the Low Head Development of the Mississippi River at Keokuk," by H. H. Tinch. Attendance 19.

Purdue University.—March 16, 1915. Electrical Building. Address by Mr. F. H. Nealis on "Lightning Protection and Arresters." Attendance 74.

March 23, 1915. Address by Prof. P. N. Evans on "The Relation of Electricity to Matter." Attendance 38.

Rensselaer Polytechnic Institute.—April 6, 1915, Sage Laboratory. Illustrated lecture on "Lightning Arresters" by E. L. Woodworth and E. W. Page. Attendance 31.

Rose Polytechnic Institute.—March 18, 1915. Paper: "Static and Lightning Protective Apparatus," by F. H. Nealis. Attendance 38.

April 13, 1915. Paper: "The Electric Furnace; Its Growth, Development and Future," by H. L. Coles. Attendance 11.

Stanford University.—March 4, 1915, Engineering Building. Address by Mr. A. B. Stuart on "Modern X-Ray Machinery." Attendance 17.

March 18, 1915. Paper: "Determination of Costs," by B. E. Ward. Attendance 15.

Syracuse University.—March 11, 1915. Paper: "Sag in Overhead Wires," by W. R. Stevens. Attendance 16.

March 18, 1915. Paper: "Salmon River Power Development," by C. J. Daly. Attendance 29.

March 26, 1915. Paper: "The Electric Furnace," by L. S. Fulmer. Attendance 16.

April 15, 1915. Paper: "Electrical Equipment of Battleships." Attendance 17.

Throop College of Technology.—March 18, 1915, Library. Illustrated address by Prof. R. W. Sorensen on "The General Electric Test Course for College Graduates." Attendance 18.

Virginia Polytechnic Institute.—March 27, 1915, Blacksburg. Illustrated lecture by Mr. C. A. Quin on "The Electrification of the N. & W. Railroad in West Virginia." Attendance 84.

Washington University.—February 25, 1915, Eads Hall. Illustrated lecture by Dr. M. von Recklinghausen on "Purification of Water by Means of the Ultra-Violet Rays." Attendance 90.

March 16, 1915, Old Chapel. Address by Mr. Thomas A. Watson on "The New Transcontinental Telephone Line." Dean Langsdorf introduced the speaker. Attendance 173.

West Virginia University.—April 2, 1915, Mechanical Hall. Discussion of recent electrical papers. Attendance 27.

Worcester Polytechnic Institute.—March 24, 1915, Electrical Engineering Building. Paper: "The Electrification of the Butte, Anaconda and Pacific Railroad," illustrated by lantern slides and moving pictures. Attendance 90.

Personal

Mr. Walter N. Cargill has been appointed Superintendent of Power and Lines for the Rhode Island Company, Providence, R. I.

Mr. Donald S. Hays of Portland, Oregon, and Miss Pansy F. Harlan of Baltimore were married on April 13, 1915. Mr. Hays is engaged in Oregon by the United States Reclamation Service, and at present resides at 644 Everett Street, Portland.

H. Whitford Jones and **Hugh Stanley Carr**, of Cleveland, Ohio, announce that the co-partnership heretofore existing between them has been dissolved. Mr. Carr has opened an office at 918 Citizens Building, Cleveland, where he will continue the general practise of consulting electrical engineering, and Mr. Jones will retain his office at 1303 Citizens Building, where he will specialize, as formerly, in industrial and municipal engineering.

Mr. O. S. More has resigned from the position of chief engineer of the Fairbanks Morse Electrical Manufacturing Company of Indianapolis, which position he has held for the past five years, in order to establish the More Electric Company, with offices in the Gas and Electric Building, Denver, Colorado. This new company will handle engineering problems as well as act as district representative for a number of well-known lines of electrical apparatus.

Mr. Aleck M. MacCutcheon, previously with the Crocker-Wheeler Company, Ampere, N. J., has recently removed to Cleveland to take charge of the design work of the Reliance Electric and Engineering Company of that city. At the time of leaving the Crocker-Wheeler Company Mr. MacCutcheon was engaged in the design of special motor-generator sets for use in radio installations. He was previously in charge of the estimating work of the engineering department and in executive charge of the drafting room.

Mr. Edwin G. Hatch has recently resigned as treasurer and manager of the Clark Electric and Manufacturing Company, New York, which position he has held since 1910, and is now associated with **Mr. Herschel C. Parker**, formerly professor of physics in Columbia University, being jointly interested with him in a number of inventions. Mr. Hatch has also, during the past year and one-half, had entire charge of Mr. Walter G. Clark's New York office, and the specification, testing and shipping of high-tension electrical material for the Victoria Falls and Transvaal Power Company, Ltd., South Africa. Mr. Hatch has not made definite plans for the future, but will probably open an office for consulting work.

Mr. Robert C. Fenner, who for the past ten years has been connected with the Cutler-Hammer Manufacturing Company, of Milwaukee, has resigned as manager of the Chicago office of that company and has opened an office of his own in the Peoples Gas Building, Chicago, where he is acting as manager of sales for a number of mechanical and electrical specialties. Mr. Fenner has been in charge of the Cutler-Hammer Chicago office for the last four years, and has taken an active part in the work of the Chicago Association of Commerce, being chairman of the electrical subdivision of that association and a member of the Ways and Means Council. He was previously located in Boston for three years as manager of the Cutler-Hammer office in that city.

.Obituary

KENGO MAKINO, Assoc. A. I. E. E., of the department of electrical engineering, Waseda University, Tokio, Japan, died on February 1, 1915, after a long illness. Mr. Makino was graduated from the Institute of Technology of Tokio in 1900, and for years identified himself in various capacities with the development of electrical industry in Japan. In 1907 he was sent to the United States and entered Cornell University, from which he was graduated in 1908 with the degree of M. E. Subsequently he entered the graduate department of the same university and in 1909 received the degree of M. M. E. He was also honored with the membership of the Sigma Xi Society. Immediately after receiving the master's degree he was summoned to his native country to organize the new department of electrical engineering of the Waseda University, which position he held to the time of his death. He was also a frequent contributor of articles on electrical engineering topics to the technical press of Japan. Mr. Makino was elected an Associate of the Institute on March 12, 1909.

GEORGE CUTTER, Mem. A. I. E. E., founder of the George Cutter Company of South Bend, Ind., died April 6, 1915, in Los Angeles, Cal., of heart failure. He had been in ill health for some time. George Cutter was born in Boston in 1853. He began his electrical work in 1869 with Johnson and Whittemore, of Boston, and made rapid progress. When the Bell telephone was brought out in 1876 Mr. Cutter was employed by Charles Williams of the Bell organization, and he was intimately associated with the introduction of this epoch-making invention. In 1881 he was in Riga and Warsaw, Russia, representing the International Bell Telephone company. In 1883 he became manager of the testing department of the Thomson-Houston Company, of New Britain, Conn. From 1885 to 1887 he was chief engineer for the same company, with headquarters in London, England. Mr. Cutter established his own manufacturing business in 1889 in Chicago, where he continued the manufacture of his own inventions and other electrical supplies until 1905, when he moved the business to South Bend and established the George Cutter Company. In December, 1911, he retired from active service with the company, turning the business over to an organization which continued the name, with Mr. Cutter as Vice-President. In 1912 he built a new home in Washington, D.C. The profits from his many successful inventions enabled Mr. and Mrs. Cutter to do a great deal of good in helping young people to get a start. Mr. Cutter was elected an Associate of the Institute on June 17, 1890, and was transferred to the grade of Member on November 18, 1896.

SIXTEN OTTO SANDELL, Assoc. A. I. E. E., died in Los Angeles, Cal., on April 7, 1915, after an extended illness. Mr. Sandell was born October 5, 1876, at Oskarshamn, Sweden. He received his preliminary education in Stockholm, and during vacations worked as an apprentice in that city and in Nürnberg, Germany. For a year he worked as an apprentice in the shops of the Allmanna Svenska Elektriska at Vesteras. He then took up the study of electrical engineering in Germany. After receiving his diploma he was draftsman and engineer for various electrical manufacturing firms in Nürnberg and Dresden. Coming to America, he served as draftsman for the Babcock and Wilcox Company, Bayonne, N. J., and the New York Edison Company. Mr. Sandell went to Los Angeles three years ago, and was connected with the Bureau of Los Angeles Aqueduct Power and then with Thomas and Post, bridge engineers. He was elected an Associate of the Institute on February 24, 1905.

Recommended for Transfer, April 1, 1915

The Board of Examiners, at its regular monthly meeting on April 1, 1915, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

Forbes, Sherman Guy, Chief Electrical Engineer to the Government of Mysore, Bangalore, India.

Hazelton, Hugh, Electrical Engineer, New York, N. Y.

Nichols, Harold E., Engineer, Research Branch, Western Electric Co., New York, N. Y.

Ruel, Amai J., Electrical Engineer, Northern Idaho & Montana Power Co., Sandpoint, Idaho.

Transferred to the Grade of Member April 9, 1915

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on April 9, 1915.

Hunt, Fred L., Chief Engineer, Turners Falls Power and Electric Co., Greenfield, Mass.

Pierce, Arthur G., District Engineer, Cutler-Hammer Mfg. Co., Pittsburgh, Pa.

Zogbaum, Ferdinand, Engineer of Maintenance, New York, Westchester & Boston Ry., New York, N. Y.

Members Elected April 9, 1915

Carpenter, Dan E., Assistant Manager, Textbook Dept., International Textbook Co.; res., 819 Richmond St., Scranton, Pa.

Coffin, Francis A., Commercial Engineer, Milwaukee Electric Railway & Light Co., 383 Public Service Bldg., Milwaukee, Wis.

Hile, Charles H., Chief of Maintenance, Boston Elevated Railway Co., 101 Milk St., Boston, Mass.

Lowenstein, Louis C., Engineer, General Electric Co., West Lynn, res., 16 Walcott Rd., Lynn, Mass.

Moore, Edward Talcott, Electrical Engineer, Westinghouse Electric & Mfg. Co., 930 University Bldg., Syracuse, N. Y.

Wier, Harry B., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

Associates Elected April 9, 1915

Amberg, Emil J., Assistant Engineer, McHenry & Murray; res., 854 Orange St., New Haven, Conn.

Anderson, Harry O., Construction Foreman, Edison Illuminating Co., Conners Creek, Mich.

Baker, George R., Construction Engineer, General Electric Co., Schenectady, N. Y.

Biggs, Robert Norman, Electrical Engineer, Devonport Ferry Co. Ltd., Auckland, New Zealand.

Bitzer, Otto F., Foreman and Electrician, Acme Wire Co., Highwood; res., 330 Blake St., New Haven, Conn.

Booth, John B., Engineer and Salesman, Woodhouse Electric Co., 51 Bank St., Norfolk, Va.

Brandt, Wm. VanC., Manager, Pittsburgh Office, Electric Storage Battery Co., 806 Keystone Bldg., Pittsburgh, Pa.

Brooke, George A., Jr., Assistant Inspector, Electric Storage Battery Co., Philadelphia; res., 5235 Archer St., Germantown, Pa.

Browning, Giles Jay, Electrician, Garner Print Works and Bleachery, Wappingers Falls, N. Y.

Champion, Charles H., General Manager, Kandem Electric Co., Inc.; res., 266 W. 77th St., New York, N. Y.

Clark, William A., Electrical Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgewood Park, Pa.

Cowdrey, William Lathrop, Mechanical Engineer, Superior Coal Co., Superior, Wyo.

Cunningham, William J., Assistant Chief Engineer, Power Dept., City of Calgary, Calgary, Alberta, Can.

Curling, Harold William, Managing Director, Canadian Union Electric Co., 130 Wellington St., Toronto, Ont.

Czarnecki, Frank C., Secretary to the President, Great Western Power Co., San Francisco; res., 4070 Opal St., Oakland, Cal.

Dichman, Ernest, Testing Radio and allied Apparatus, Mare Island Navy Yard; res., Edge Hill, St. Helena, Cal.

Dobson, John Vernon, Railway Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 405 West St., Wilkinsburg, Pa.

Edwards, George L., General Superintendent, Stayton Electric Light Co., Stayton, Ore.

Farnham, William Ellis, Local Traffic Engineer, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

Floyd, Frank T., Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 807 St. James St., Pittsburgh, Pa.

Frost, Leslie E., Railway Engineering Div., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Gaffey, John J., Electrical Designer, Stone & Webster Engineering Corp., Boston; res., 157 Cypress St., Brookline, Mass.

Gardner, Fulton Q. C., Captain, Coast Artillery Corp, United States Army, Fort Totten, N. Y.

Grierson, Clarence Ivan, Electrical Engineer, Wabamun Power and Coal Co.; res., 9934 86th Ave., Edmonton, Alta.

*Hamilton, Robert F., Testing Dept., British Westinghouse Co., 46 Moreton Ave., Stretford, Manchester, England.

Harris, James A., Assistant Engineer of Distribution, Toronto Electric Light Co.; res., 90 Campbell Ave., Toronto, Ontario.

Harrison, William T., Secretary, Hesse-Martin Iron Works, 434 Belmont St., Portland, Ore.

*Harvey, Harold G., Street Work Recorder, Commonwealth Edison Co., Chicago; res., 311 S. Ridgeland Ave., Oak Park, Ill.

*Hoot, Denver Wayne, Test Dept., General Electric Co.; res., 1 Elmer Ave., Schenectady, N. Y.

*Huff, Jesse, Assistant Operator, Utah Light & Power Co., Olmstead, via Provo, Utah.

Hull, Blake D., Transmission & Protection Engineer, Southwestern Bell Telephone System, St. Louis, Mo.

Irey, George W., Central Station Operating Engineer, St. Joseph Ry., Lt., Heat & Pr. Co.; res., 2413 N. 7th St., St. Joseph, Mo.

Jefferson, Robert Dewey, Foreman System Operator, Idaho Railway Light & Power Co., Boise, Idaho.

Johnson, Manfred J., Electrical Experimental Dept., The Bristol Co., Waterbury; res., 1 New St., Naugatuck, Conn.

Koppel, Julius George, Superintendent, Sault Ste. Marie Bridge Co., Sault Ste. Marie, Mich.

Lee, Benjamin F., Electrical Superintendent, Cliff Electrical Distributing Co. and Hydraulic Power Co., Niagara Falls, N. Y.

*Lloyd, William E., Jr., Supt. of Operation and Distribution, Lehigh Navigation Electric Co., Martins Creek, Pa.

Lunsford, Jesse B., Test Dept., Crocker-Wheeler Co., Ampere; res., 169 N. 12th St., Newark N. J.

*Mabbs, John K., Electrical Draftsman, Commonwealth Edison Co.; res., 5300 Kenmore Ave., Chicago, Ill.

Monkhouse, Allen, Superintendent, Railway Dept., Russian Electric Co. "Dynamo" Ltd., Moscow, Russia.

*MOORE, WILLIAM D., Division Superintendent of Plant, Pacific Telephone and Telegraph Co., Portland, Ore.

MORROW, ALLEN, Research and Efficiency Engineer, Standard Oil Co., Richmond; res., 2634 Dana St., Berkeley, Cal.

O'NEILL, THOMAS FRANCIS, Electrical Supervisor, Winchester Repeating Arms Co.; res., 455 Washington Ave., New Haven, Conn.

PEART, JOHN W., Draftsman, Hydro-Electric Dept., City of London, London, Ontario.

*POLLARD, JAMES F., Power House Operator, Pacific Gas & Electric Co., Drum, Placer Co., Cal.

POSA, ENRIQUE, Electrical Engineer, A. E. G. Thomson-Houston, Iberica; res., Paseo San Juan 57, Barcelona, Spain.

*RAMSAY, LOUIS MICHAEL, Test Man, General Electric Co.; res., 821 Main St., Schenectady, N. Y.

RESE, WILLIAM F., Chief Electrician, Weirton Steel Co., Weirton, W. Va.

RIDDELL, JAMES L., Supt., Line & Cable Dept., Keystone Telephone Co., 135 S. 2nd St., Philadelphia, Pa.

SMITH, LEWIS, Rumford Falls Power Co., Rumford, Me.

SPAHR, CHARLES W., Chief Engineer, Mitchell-Lewis Motor Car Co., Racine, Wis.

STEPHENSON, JOSEPH, Engineer, Gas Dept., Columbia Railway, Gas & Electric Co., Hampton Ave., Columbia, S. C.

THOMSON, STANLEY E., Construction Engineer, Toronto Power Co., 5 Stamford St., Niagara Falls, Ont.

UPTEGRAFF, ROY E., Electrical Engineer, Pittsburgh Transformer Co.; res., 1711 Termon Ave. N. S., Pittsburgh, Pa.

VANDERHOOF, CHARLES N., Foreman, Electrical Construction, Public Service Electric Co.; res., 59 N. 6th St., Newark, N. J.

WALLIS, CYRIL THORNTON, Test Room Assistant, Taylor Instrument Cos.; res., 139 Garfield St., Rochester, N.Y.

WILSON, JOHN, Chief Electrician, Simplex Wire & Cable Co., 63 Sidney St., Cambridge, Mass.

*WINSTON, WILLIAM O., JR., Agent, Winston Bros. Co., 801 Globe Bldg., Minneapolis, Minn.

YOUNG, JAMES A., Electrical Construction Foreman, General Electric Co., Atlanta, Ga.

Total 59.

*Former enrolled students.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1915.

Adair, W. R., Mars, Pa.
Atkinson, G. W., Washington, D. C.
Banzhof, C. P., Lancaster, Pa.
Beall, F. H., Cambridge, Mass.
Benjamin, L. S., St. John, N. B.
Benney, G. A., Pittsburgh, Pa.
Benson, C. F., Chicago, Ill.
Borden, S. W. (Member), Summit, N.J.
Bradley, H. L., Milwaukee, Wis.
Brophy, J. J., Peabody, Mass.
Caigan, I., Boston, Mass.
Clark, F. H., Salt Lake City, Utah
Cole, K. E. N., St. Louis, Mo.
Dailey, J. B., Detroit, Mich.
Davis, J. M. (Member), WestLynn, Mass.
Dawe, H. S., Ashburton, N. Z.
de Angelis, M. L., Paris, France
Duke, H. T., Jr., Philadelphia, Pa.
Ferguson, G. F., Christchurch, N. Z.
Furuichi, T., Boston, Mass.
Gurdes, F. A., Chicago, Ill.
Harrold, A. E. (Member), Cleveland, O
Hersh, W. L. (Member), Gatun, C. Z.
Hewitt, A. C., Hagerstown, Md.
Honegger, A., Schenectady, N. Y.
Hornback, F. S., Black Diamond, Alta.

Horton, R. S., Oakland, Cal.
Inagaky, T. Y., Columbus, O.
Irvin, R., Salmon, Idaho
Irvine, T. F., Wheeling, W. Va.
Irwin, H. W., Boston, Mass.
Jacobi, E. N., Milwaukee, Wis.
Kimball, C. B., Boston, Mass.
Knost, C. P., Mogollon, N. M.
Krotzer, F. W., Milwaukee, Wis.
Kutschera, A. J. (Member), Milwaukee, Wis.
Lauridsen, L., Portland, Ore.
Leeson, W. A., Rancagua, Chile
Liljenroth, F. G., Vesteras, Sweden.
Lindsay, H. D., Milwaukee, Wis.
Lytle, L. B., Rossland, B. C.
MacBurney, J. L., Philadelphia, Pa.
Mainland, J., Holden, W. Va.
Malmborg, C. A., Lehigh, Iowa
Moore, D. H., Pittsfield, Mass.
Odena, F. M., Jr., Detroit, Mich.
Owens, E. T., Balboa Heights, C. Z.
Peake, K. C., Newark, N. J.
Philbrick, J. S., Bolinas, Cal.
Sargent, P. G., St. Louis, Mo.
Schluter, W. H. F., Brooklyn, N. Y.
Vickers, C. H., Chicago, Ill.
White, C. D., Boston, Mass.
Whiting, H. R., Guayama, P. R.
Total 54.

Students Enrolled April 9, 1915

7258 Eshbach, O. W., Lehigh Univ.
7259 Martin, H. A., Univ. of Virginia.
7260 Goodwin, W. C., Penna. St. Coll.
7261 Mueller, J. T., Marquette Univ.
7262 Goldstene, A. B., Cooper Union.
7263 Sweigart, C. F., Ohio North. Univ.
7264 Zollinger, J. E., Univ. of Illinois.
7265 Whiteman, C. A., Penna St. Coll.
7266 Makin, H. B., Univ. of Alabama.
7267 Elliott, H. F., Stanford Univ.
7268 Baker, M.P., Stanford University.
7269 Wormser, P., Stanford University.
7270 Pier, A. B., Stanford University.
7271 Daniels, H., Harvard University.
7272 Perry, A. C., Univ. of Cincinnati.
7273 Yocum, G.G., Univ. of Cincinnati.
7274 Kyle, G. L., Univ. of Illinois.
7275 Dix, E. J., Univ. of Illinois.
7276 Patteson, G. P., Va. Poly. Inst.
7277 Moore, J. H., Univ. of Va.
7278 Rathbun, H. J., Stanford Univ.
7279 Church, G. H., Highland Park Coll.
7280 Moline, E. L., Highland Park Coll.
7281 Schwensen, F.H., Highland Pk. Coll
7282 Wilson, G., Highland Park Coll.
7283 Maconnell, W.E., Highland Pk. Coll
7284 Hutchison, W. M., Penna. St. Coll.
7285 Mok, K. Y., Yale University.
7286 Dible, H. J., Univ. of Pittsburgh.
7287 Stitt, R. de V., Univ. of Illinois.
7288 Vetter, N. J., Yale University.
7289 Tate, J. A., Univ. of Wisconsin.
7290 Raube, W.C., Univ. of Wisconsin.
7291 Reed, J.W., Univ. of Wisconsin.
7292 McManigal, R. D., Jr., Lafayette Coll.
7293 Trummell, M. F., Univ. of Va.
7294 Horst, A. C., Penna St. Coll.
7295 Schott, R. C., Ohio State Univ.
7296 Eck, L. E., Ohio State Univ.
7297 Miner, D. F., Worcester Poly. Inst.
7298 Silver, B. L., McGill University.
7299 Hansen, V., Univ. of Washington.
7300 Haselton, M. L., Worcester Poly. Inst.
7301 Dunn, E., Rose Poly. Institute.
7302 Turner, W. F., Rose Poly. Inst.
7303 Bundy, E. E., Rose Poly. Inst.
7304 Hess, E. E., Rose Poly. Inst.
7305 Chandler, C. H., Jr., Univ. of Va.
7306 Ball, W. L., Univ. of Virginia.
7307 Ritchie, T. C., Univ. of Virginia.
7308 Robinson, H. H., Ohio Northern Univ.
7309 Van Zandt, J. P., Univ. of Cal.
7310 Smith, G. L., Colorado Agri. Coll.
7311 Smith, H. D., Washington Univ.
7312 Dolch, B. E., Washington Univ.
7313 Fitzgerald, G. L., Kans. State Agricultural College
7314 Smith, C.C., Kans. State Ag. Coll.
7315 Jackson, P. E., Kans. St. Ag. Coll.
7316 Mote, C. A., Univ. of Michigan.
7317 Toncray, M. H., Univ. of Mich.
7318 Greene, C. R., Univ. of Michigan.
7319 Cowin, S. H., Case Sch. App. Sci.
7320 Benz, W. K., Univ. of Pittsburgh.
7321 Hursh, J. I., Purdue University.
7322 Ashley, R.W., Purdue University.
7323 Potter, E. V., Univ. of Illinois.
7324 Finley, R. H., Univ. of Nebraska.

7325 Robinson, J. D., Swarthmore Coll.
7326 Newill, E. B., Georgia Sch. Tech.
7327 Darby, F. W., Georgia Sch. Tech.
7328 Costello, J. C., Univ. of Calif.
7329 Stehman, E. H., Carnegie Inst. Technology.
7330 Enlind, C. J., Ohio Nor. Univ.
Total 73

EMPLOYMENT DEPARTMENT

NOTE: Under this heading brief announcements (not more than 50 words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months, during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Vacancies

V-63. Good opportunity for engineer with executive ability possessing experience in the construction and maintenance of underground conduit systems.

The United States Civil Service Commission announces an open competitive examination for electrical expert aid (ship), on May 12, 1915, to be held at numerous places in the United States. From the register of eligibles resulting from this examination certification will be made to fill a vacancy in this position in the Department of Construction and Repair, Washington, D. C., at a salary of $4 per diem, and vacancies as they may occur in positions requiring similar qualifications at any United States naval establishment, unless it is found to be in the interest of the service to fill any vacancy by reinstatement, transfer, or promotion.

The duties of this position require a theoretical knowledge of all kinds of electrical apparatus used on board naval vessels, capability of preparing specifications and requisitions for electrical material for ships undergoing construction and repairs, making of tests of electrical auxiliaries in use on shipboard, and of estimating the time, material and cost of making repairs of electrical equipment on ships.

Persons who meet the requirements and desire this examination should at once apply for the circular announcing this examination (Form No. 343, issued April 3) and Form No. 1312, stating the title of the examination for which the form is desired, to the U. S. Civil Service Commission, Washington, D. C.

The Municipal Civil Service Commission of the City of New York announces an examination for Fire Telegraph Expert at a salary of $3000 per annum. Candidates must be familiar with electrical principles and laws involved in electrical signaling practise and electrical engineering. They must have had five years' experience with fire alarm telegraph apparatus, as designer or in other responsible technical position; must be familiar with auxiliary fire alarm service, automatic alarms and electrical supervision of sprinkler systems, watchman and fire combination service. Graduation from technical school of standing will count as one years' experience.

The subjects and weights are: Technical, including report, 5; Experience, 5; 75 per cent required on Technical and 70 per cent on Experience.

Applications will be received at room 1400, Municipal Building, New York City, from April 30 to May 14, at 4:00 p.m.

A qualifying physical test will be held. The minimum age is 21 years. There is one vacancy in the Fire Department. Four cents postage should accompany request for application blanks by mail.

Men Available

251. Teacher of Electrical Engineering, with successful practical and teaching experience, open for engagement September 1. Experience covers manufacturing, operating and consulting work. Assoc. A. I. E. E., and member of S. P. E. E. and N. E. L. A.

252. Electrical Engineer. University graduate; ten years' experience testing, assistant electrical engineer

steel company; chief electrician large ice plant; also glass company. Planned installed, and operated 6000-kw. power system, including substations. Will accept position as chief electrician industrial works or assistant electrical engineer power or light company.

253. Electrical Engineer. Graduate University of Michigan 1910. Two years with Westinghouse Co. Two years surveying and valuation work. Now engaged in drafting under Civil Service. Desire position as instructor in electrical engineering. Salary no object if position is permanent with opportunity for advancement. Prefer Middle West.

254. Engineer and draftsman desires position as chief electrician with concern, or position as superintendent with electric light company in New England. At present employed; age 31. Four years' experience in hydroelectric, high-tension, switchboard design and industrial layouts. Five years' experience in construction, operation and maintenance.

255. Electrical Designing Engineer. Mem. A. I. E. E. Technical graduate; six years' experience as responsible designer of large electrical machinery and transmission systems. Desires position with firm of consulting or contracting engineers.

256. Experienced all-round electrician. Two years assembling and winding electric machinery; two years testing department; three years traveling, shooting trouble, repairing and installing electric equipment; three years charge of fifty men repairing and testing all kinds of electric equipment for large electrical manufacturing company. Age 31; married.

257. Graduate Mechanical Engineer. Post-graduate work in efficiency engineering at Harvard University; drafting room, pattern and machine shop experience. Desires position as assistant superintendent, with an opportunity for advancement by conscientious work and proper initiative in superintending and increasing the efficiency of production.

258. Assistant Professorship of Electrical Engineering desired by Mass. Inst. Tech. graduate, age 26. Two years' experience as college instructor and two years in commercial and electrical practise.

259. Electrical Engineer. Four and a half years' experience; one as instructor; two as equipment man and line inspector for large telephone company; one and a half in instrument calibration, development work and installation of new electrical gas meter for prominent Middle West concern. Graduate Univ. Penna. Consider any kind of engineering work, any location.

260. Hydroelectric Engineer. Cornell graduate; fifteen years' practical experience in designing and constructing power systems, irrigation and general contracting. War caused loss on contracts and delay in appointment to chief engineer's position on large irrigation project. Single, of good personality, and will take anything or go anywhere.

261. Electrical Engineer. Age 27; single; absolutely reliable, energetic; graduate Stanford University, 1912. Three years' varied experience with construction companies, Western hydroelectric developments. Valuation. Desires position with construction or power company, consulting engineer, or charge of industrial plant. Open for engagement to any reasonable offer. Location no object.

262. Engineer. Age 35; married. Fifteen years' field experience in electrical engineering. Specialist in erection and maintenance of large storage battery plants, also of buildings. A keen student of costs and efficiency. Executive, energetic, good reorganizer. Desires responsible position.

263. Electrical Engineer. Graduate six-year course Univ. Wis., E. E. Age 30; married. Practical experience as foreman, superintending power house construction on high-tension system. Past three years instructor in a university. Desires change of location—North or West preferred.

264. Electrical Engineer desires position in South America on operation or construction. American; 5½ years' experience operation in United States; 5 years' experience Mexico operation, construction, commercial engineering, etc. Now employed in foreign country; speaks Spanish; Mem. A. I. E. E.

265. Electrical Engineer. Technical graduate; age 27; desires position as assistant to electrical engineer or with construction engineer. 2½ years General Electric test; 3 years wiring and station construction. Fair estimator. No objection to foreign service.

266. Electrical Superintendent, having charge of 3000-kw. plant and overhead lines in town of 30,000, wishes change. Experience in the maintenance of a-c. lines, trolley and power house, and in keeping down cost.

267. Engineering position with public service or manufacturing company desired by technical graduate of ten years' experience in engineering, estimating and drafting on switchboards, power stations and factory equipment.

268. Member A. I. E. E. and A. S. M. E. Technical graduate; age 35. Fourteen years' practical experience in design, construction, operation and maintenance of hydroelectric and steam power plants, high-tension transmission, distribution. Opportunity desired where character and ability count; salary secondary consideration; immediately available; will go anywhere.

269. Electrical Engineer. Thirteen years' experience with prominent consulting engineers of New York City. Knowledge of heating, elevators, office routine, mechanical drafting; can write specifications, supervise installations, test same and estimate. Teach in evening school in New York. Desire position with architect, builder or engineer.

270. Graduate (1914) from mechanical and electrical engineering course (degree B. E.) desires position with consulting engineer. Seeks place where he will be thrown in contact with experienced engineers, hydroelectric work preferred. At present operating hydroelectric plant, but can leave on reasonably short notice.

271. Electrical Engineer. 1914 graduate. Desires position with operating, consulting or construction company. Willing to work up from the bottom. Good clean habits. Good references as to industry and character. Salary and location not primary objects if there are good prospects for a worker.

272. Electrical Engineer. University graduate, with eight years' practical experience, including four years with Westinghouse Co. in their several testing departments and on the road in their service department. Can make industrial layouts and estimate costs. Not particular as to location or work if chance for advancement is afforded.

273. Electrical Engineer. Young man technical graduate, two years General Electric test and two years in sales department of district office. [illegible] six months as meter [illegible] service corporation. Desires permanent position with operating or manufacturing company, Pacific coast or Middle West preferred.

274. Operator. Desires position in Argentina. [illegible] years' operating experience in large hydroelectric and steam-electric plants. Degree B. S. E. E. Now employed; could soon speak Spanish.

275. Practical all-round electrician desires position. Age 32; married. Three years technical education and fourteen years' practical experience in construction work of all kinds; power house and factory maintenance. Can handle men.

276. Electrical and Mechanical Engineer. Age 31; graduate Univ. Ill. 1907. Desires position with firm of consulting engineers. Have been in present position four years, designing modern steam and electric drainage pumping plants. Considerable experience in making mechanical investigations and reports. Western location preferred.

277. Electrical Engineer. Eighteen years' training and experience, embracing Westinghouse factory and four years test. Last eight years with large S. A. corporation in various positions of progressive responsibility, both construction and operation. Desire commercial engineering position with manufacturer in foreign department, or light and power company manager or superintendent.

278. Electrical Engineer. Technical education; thorough training, theoretical and practical, in operation and design of electrical power installations. Seven years with Westinghouse Co. Four years as electrical engineer for prominent firm of consulting industrial engineers. Can accept position of responsibility on short notice.

279. Mechanical-Electrical Engineer. Cornell graduate. Three years as assistant manufacturing and commercial engineer in turbine and motor departments General Electric Co. Employed in consulting and sales capacity by prominent heating and ventilating engineering concern. Business man; acquainted New York City and Boston. Desires permanent sales, manufacturing or consulting connection.

280. Electrical Engineer. Age 32, technical education, ten years' practical experience. Expert on management of construction and operation of electrical apparatus connected with large industrial plants. Can show efficiency with minimum cost and delay. Now connected in above capacity. Best of credentials; location no object.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Electric Railway Association. Proceedings, 1914. (5 vols.) New York, 1914. (Exchange)

——Yearbook, 1914-15. New York, 1914. (Exchange.)

Annuaire Francais de L'Electricité, 1914. Paris, 1914. (Gift of Lumière Electrique.)

Appraisal of Public Utility Properties. By Wm. G. Woolfolk. (Read before the 7th Annual Convention Indiana Gas Association, March 10-11, 1915.) (Gift of Sanderson & Porter.)

Association of Iron and Steel Electrical Engineers. Proceedings. 1914. (Exchange.)

Chicago. Department of Gas and Electricity. Annual Report 17th, 1913. Chicago, 1914.

——Report to the Committee on gas, oil and electric light on the Investigation of the Commonwealth Edison Company, May 1913. Chicago, 1913. (Gift of Chicago Department of Gas and Electricity.)

Gas, Electric and Street Railway Association of Oklahoma. Papers presented at the 1st annual Convention. n.p. n.d. (Gift of Association.)

Schweizerischen Elektrotechnischen Vereins. Jahresheft. 1914-15. Zürich, 1915. (Exchange.)

Society of Chemical Industry. List of Members, 1915. London, 1915. (Gift of Society.)

Western Union Telegraph Company. Annual Report 1914. New York, 1915. (Gift of Western Union Telegraph Co.)

Gift of American Telephone and Telegraph Company, Annual Report, 1914. New York, 1915. Development of the Telephone in Europe. By H. L. Webb. Five Minute Talks on Government Ownership. Talk no. 1-3. Shall the Government own and Operate the Railroads, the telegraph and telephone systems? The Negative Side. 1915.

Shall the Government Own the Telephones and the Telegraph? (Reprinted from the *Metropolitan*, Dec. 1914.)

TRADE CATALOGUES

Chicago Pneumatic Tool Co. Chicago, Ill. Bull. 34-M. Class "O" Chicago. Pneumatic steam and power driven compressors. March 1915.

Fort Wayne Electric Works of General Electric Co. Fort Wayne, Ind. Bull. 45201. Type A transformers of large capacities. June 1914.

——46100. Type M demand indicators. Feb. 1915.

——46101. Type P demand indicators. Feb. 1915.

——48100. Commutating pole direct current crane and hoist motor CO1800-line. July 1914.

General Electric Co. Schenectady, N. Y. Y-604. Electric household appliances.

Goldschmidt Thermit Co. New York, N. Y. Reactions. vol. 8, no. 1.

Klöckner, F. Köln-Bayenthal. Price List of manufacturers. 1915.

Leeds & Northrup Co. Philadelphia, Pa. Bull. 235. Vibration galvanometer.

National Lamp Works of General Electric Co. Cleveland, Ohio. Bull. 15B. Lighting of Billboards and large painted signs. 1915.

Philadelphia Electric Co. Philadelphia, Pa. Bulletin March 1915.

Standard Underground Cable Co. Pittsburgh, Pa. Bull. 201-1. Standard C.C.C. wire. March 1915.

Steel City Electric Co. Pittsburgh, Pa. March-and clamps.

Westinghouse Machine Co. East Pittsburgh, Pa.

——514. Westinghouse horizontal Gas engines. Feb. 1915.

——515. Refrigerating apparatus. Feb. 1915.

UNITED ENGINEERING SOCIETY

Alliages et Fonderie de Bronze. By Victor Marteil. Paris, 1910. (Purchase.)

Applied Mechanics. Ed. 9. By G. Lanza. New York, 1910. (Purchase.)

Bibliographie der Deutschen Zeitschtiften Literatur. Band XXXIV, 1914. Leipzig, 1914. (Purchase.)

Bibliographie der Deutschen Zeitschriften Literatur Ergänzungs Band VII (Band XXXV A.) Leipzig, 1914. (Purchase.)

Biographical Directory of the Railway Officials of America. 1913 edition. New York, 1913 (Purchase.)

Calculus and its applications. By R. G. Blaine. New York, 1914. (Purchase.)

Cellulose. By Cross & Bevan. London, 1910. (Purchase.)

Chemistry and its Borderland. By A. W. Stewart. Lond. N. Y., 1914. (Purchase)

Chemistry of Pigments. By E. J. Parry and J. H. Coste. Lond., 1902. (Purchase.)

Civil Engineering Specifications and Contracts. By R. I. D. Ashbridge. Chicago, American Technical Society, 1914. (Gift of author.)

The author has developed a logical system of preparing specifications, including typical specifications for railroad work, bridges, culverts, excavations, fills, tunnels, roadbeds, country roads, and city paving. Forms for proposal, agreement and contracts are discussed and illustrated. W.P.C.

Efficient Cost Keeping. Ed. 3. By E. St. Elmo Lewis. Detroit, Burroughs Adding Machine Co., 1914. (Gift of Publisher.)

One of a type of books of real value issued to advertise the uses of the machine made by this company, but only as an incident in a well-written and useful treatise on cost keeping. The work is a distinct contribution to the literature of efficiency in management. W.P.C.

Evolution of the Steam Locomotive, 1893-1898. Ed. 2. By G. A. Sekon. London, 1899. (Purchase.)

Gas Engines. By W. J. Marshall and H. R. Sankey. Lond., 1911. (Purchase.)

Index to Specifications issued by the Navy Department for Naval Stores and Material, Jan. 2, 1915. Wash., 1915. (Gift of U. S. Navy Dept.)

Investigations and Experimental Researches for the Construction of my large oil-engine. By H. Junkers. London, n.d. (Purchase.)

Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt III Band 1914. I. Leiferung. Berlin, 1914. (Purchase.)

List of American Doctorial Dissertations printed in 1913. By Alida M. Stephens. Wash., Govt., 1914. (Gift of authoress.)

Manufacture and Comparative Merits of White Lead and Zinc White Paints. By G. Petit, translated from the French by Donald Grant London, 1907. (Purchase.)

Manufacture of Paint. Ed. 2. By J. C. Smith. London, 1915. (Purchase.)

Manufacture of Varnishes and Kindred Industries, Ed. 2, volume I. By J. G. McIntosh. Lond., 1914. (Purchase.)

Marine Boiler Management and Construction. Ed. 4. By C. E. Stromeyer. London-New York, 1914. (Purchase.)

McGraw Electrical Directory. Electric Railway Edition, Feb. 1915. New York, 1915. (Purchase.)

Michigan Engineer. 1896-1902. (Gift of Michigan Engineering Society.)

Moody's Manual of Railroads and Corporation Securities. Volume I, 1915. New York, 1915. (Purchase.)

New York Mineralogical Club. Bulletin no. 3. Minerals of Broadway, New York, City. May, 1914. (Gift of Club.)

Ordnance and Gunnery. By O. M. Lissak. New York, 1914. (Purchase.)

Petroleum Year Book, 1914. London, 1914. (Purchase.)

Popular treatise on the colloids in the industrial arts. By Kurt Arndt. Easton, 1914. (Purchase.)

Practical Well Sinking. By B. A. Harrison. London, 1913. (Purchase.)

Principles of Metallurgy. Ed. 2. By A. H. Hiorns. Lond., 1914. (Purchase.)

Sur la Production, la Distribution, et l'emploi de L'Electricité par les Charbonnages. By Félix Leprince-Ringuet. Paris, 1912. (Purchase.)

Projectile throwing engines of the ancients, a summary of the history, construction and effects in warfare. By R. Payne-Gallwey. New York, 1907. (Purchase.)

Railways of the World. By Ernest Protheroe. Lond., N. Y. n.d. (Purchase.)

Report of the Joint Committee of New York & Brooklyn Scientific Societies on Standard Sizes for trays, cabinets, etc. approved Apr. 21, 1894. (Gift of New York Mineralogical Club.)

Report on Detroit Street Railway Traffic and Proposed Subway made to Board of Street Railway Commissioners City of Detroit. By Barclay Parsons & Klapp. New York, 1915. (Gift of Barclay Parsons & Klapp.)

River and Canal Engineering. By E. S. Bellasis. London, 1913. (Purchase.)

Sanitary Engineering. Ed. 3. By Francis Wood. London, 1914. (Purchase.)

Steam Boiler Construction. Rules of the National Boiler and General Insurance Co. Ltd. By E. G. Hiller. Manchester, 1912. (Purchase.)

Trow's New York City Directory, 1915. New York, 1915. (Purchase.)

Waterworks Engineering. By Fred C. Curen. Bristol, 1914. (Purchase.)

OFFICERS AND BOARD OF DIRECTORS, 1914-1915

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(Term expires July 31, 1915.)

PAUL M. LINCOLN.

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(Term expires July 31, 1915.)	(Term expires July 31, 1916.)
RALPH D. MERSHON.	C. O. MAILLOUX.

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(Term expires July 31, 1915.)	(Term expires July 31, 1916.)	(Term expires July 31, 1917.)
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CARL HERING, 1900-1.
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DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13
C. O. MAILLOUX, 1913-14.

***Deceased.**

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Revised to May 1, 1915

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and the chairmen of all Institute Sections

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C. A. Adams, Secretary,
Harvard University, Cambridge, Mass.
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H. W. Fisher, L. T. Robinson,
H. M. Hobart, E. B. Rosa,
F. B. Jewett, C. E. Skinner,
P. Junkersfeld, J. M. Smith,
G. L. Knight, H. G. Stott,
W. L. Merrill, P. H. Thomas.
and the Chairman of the Code Committee, *ex-officio.*

CODE COMMITTEE.

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J. C. Forsyth, H. R. Sargent.
H. B. Gear, A. M. Schoen,
H. O. Lacount, George F. Sever,
Kempster B. Miller, C. E. Skinner,

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Charles L. Clarke, Paul Spencer,
C. E. Scribner, Charles A. Terry.

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Revised to May 1, 1915

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W. S. Gorsuch, C. S. MacCalla,
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A. S. Loizeaux, Paul Spencer,
C. F. Uebelacker.

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E. J. Berg, V. D. Moody,
[illegible] F. D. Nims,
[illegible] F. W. Peek, Jr.,
[illegible] Harold Pender,
[illegible] K. C. Randall,
[illegible] C. S. Ruffner,
[illegible] F. D. Sampson,
[illegible] P. W. Sothman,
[illegible] C. E. Waddell,
[illegible] E. Woodbridge.

RAILWAY COMMITTEE.

D. C. Jackson, Chairman,
[illegible] Street, Boston, Mass.
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Pittsfield	Mar. 25, '04	W. W. Lewis	M. E. Tressler, General Electric Company, Pittsfield, Mass.
Portland, Ore.	May 18, '09	R. F. Monges	Paul Lebenbaum, 45 Union Depot, Portland, Ore.
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Arkansas, Univ. of	Mar. 25, '04	D. C. Hopper	J. E. Bell, Univ. of Arkansas, Fayetteville, Ark.
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California Univ. of	Feb. 9, '12	J. V. Kimber	H. S. Mulvaney, 1521 Hopkins Street, Berkeley, Cal
Cincinnati, Univ. of	Apr. 10, '08	F. Oberschmidt	A. C. Perry, 707 East McMillan Street, Cincinnati, O.
Clemson Agricultural College	Nov. 8, '12	W. E. Blake	F. L. Bunker, Clemson College, S. C.
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Iowa State College......Apr. 15, '03	Roscoe Schaffer	F. A. Robbins, Iowa State College, Ames, Iowa.
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Lehigh University......Oct. 15, '02	N. F. Matheson	F. C. Brockman, 3 North Main St., Nazareth, Pa.
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SECTION II

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of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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Presented at the 308th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 16, 1915.

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(*Subject to final revision for the Transactions.*)

DIRECT-CURRENT CONTROL FOR HOISTING EQUIPMENT IN INDUSTRIAL PLANTS

BY W. T. SNYDER

Abstract of Paper

In selecting a controller for application to various types of mill machinery all the conditions must be considered, such as the class of operator, conditions of location, operation and maintenance, relative importance of reliability, simplicity, cost and repairs, etc., and initial cost. These points are illustrated by three different types of control as applied to a blast furnace skip hoist, to a high-speed coal hoist, and to a slow-speed ash hoist. In the first case reliability and continuity of operation are imperative, and other requirements are of secondary importance; in the second case, where an ordinary delay does not affect plant operation, questions of simplicity, repairs, maintenance and inital cost can be given more consideration, as continuity of operation is not absolutely essential; in the third case where the operations are performed by unskilled labor the most important requirements are that the controller perform its functions positively, accurately and automatically, and it should be provided with all the necessary protective features to avoid damage to the apparatus controlled.

IT IS the purpose of this paper to describe briefly the controllers on a few different types of hoisting equipment, and point out some of their advantages and disadvantages, also to point out what, in the writer's opinion, are good points to be desired, as well as the undesirable features to be avoided in selecting a controller for the different classes of service.

Blast-Furnace Skip Hoist

A description of a particular skip hoist and controller is given below, Fig. 1 showing a general arrangement of the skip, cars, and hoist.

The hoist is driven by a 175-h.p. 300-rev. per min., 230-volt, compound-wound d-c. motor, geared to two drums, each mounted on a common shaft. One of these drums winds up the hoisting cable while the other is unwinding; one car being at the top of the incline when the other is at the bottom.

When the power is shut off the hoist, a solenoid-operated

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band brake is automatically applied. The solenoid is shunt wound and is energized by the closing of the reverse switches, and released upon their opening. The amount of power and time required through an operating cycle is shown in Fig. 2.

As is shown on this curve, which was taken under normal operation, the time required to hoist the car to the top of the furnace and dump it is 40 seconds. If for any reason faster charging is desired, this time can be reduced to 33 seconds per trip by adjusting the accelerating relay to shorten the time for acceleration, and also, by making a slight adjustment, resistance is automatically inserted in the shunt field circuit immediately following the last point of acceleration, and is cut out again just before reaching the normal slow-down point. When not needed, it only requires a moment to make the necessary adjustments to allow the hoist to operate at normal speed.

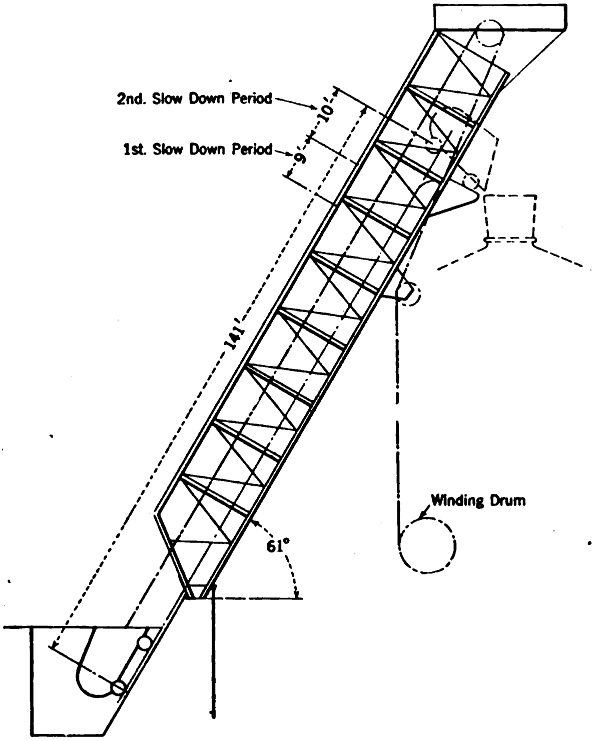


FIG. 1—SKIP HOIST FOR 500-TON BLAST FURNACE

Should the hoist cable become slack for any reason, such as a descending car stopping on account of derailment, broken axle, etc., before it reaches the bottom, or if one of the duplicate cables should break, the sagging cable will open an electrical contact which will immediately cut off the power, and the motor comes to rest.

To the hoist drum shaft is geared a contact arm which travels over a dial on which there are contacts that control some of the operations of the main controller after the operator, who is located forty feet away, throws on the master controller to start.

To the motor shaft is connected a small generator, the voltage of which varies with speed of the hoist up to 70 volts maximum. Across the terminals of this generator is connected a relay which varies the resistance that is connected in multiple with the armature of the hoist motor at the slow-down point. This is accomplished by adjusting the relay so that it will operate, when a load of coke or an empty car is being hoisted, and cut out at this point a section of the resistance that is connected in multiple with the hoist armature.

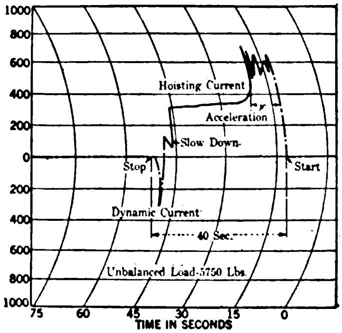


Fig. 2—Skip Hoist—one 175-h.p. Compound-Wound Motor, 230 Volts, 300 rev. per min., 654 Amperes

When a heavier load is being hoisted, the speed of the hoist is reduced, in consequence of which the voltage from the small generator is not high enough to operate the relay, and all the resistance is permitted to be in circuit across the terminals of the hoist armature, thereby producing less retarding effect at this point.

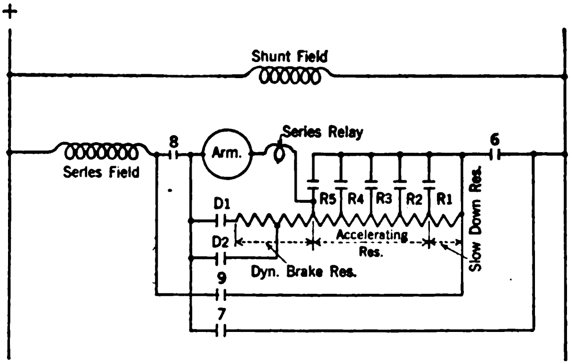
While the permissible overtravel is 28 in., the actual variation in the stopping point, with this simple slow-down arrangement, does not exceed five in., and is due to the slip of the brakes on the various weights of load.

A simplified wiring diagram of the connections of the motor and controller and a chart showing the sequence of operation of controller switches is shown in Fig. 3.

This controller is located in the same building as the hoisting machinery. It is inspected and given any necessary attention the same as all other electrical apparatus.

During the past four years, the entire electrical equipment in connection with this skip hoist, including motor, controller, and wiring, has caused a stop of 55 minutes on the furnace, and was due to paraffine running out of a relay coil and getting on a secondary contact, thereby insulating the contact and causing the controller to fail to start. Most of the time was spent in hunting the trouble. With proper arrangement of terminals this fault could have been found by test in a very short time.

When it is considered that the skip averages 16 trips per hour, seven days each week, and that the controller goes through the different operations of the cycle each time entirely automatically; accelerates, slows down, and stops, with no further attention after it is started by the operator closing the master switch, the degree of reliability that can be obtained with a modern controller is evident.



Sequence of Switches

No.1 Skip Car Up No.2 Skip Car Down										No.1 Skip Car Down No.2 Skip Car Up							
Sw.	Slow Down			Accelerating					Off	Accelerating					Slow Down		
R1	2nd.		1st.	○	○	○	○	○		○	○	○	○	○	1st.	2nd.	
R2				○	○	○	○				○	○	○	○			
R3				○	○	○						○	○	○			
R4				○	○								○	○			
R5				○										○			
6	○	○	○	○	○	○	○	○									
7										○	○	○	○	○	○	○	○
8	○	○	○	○	○	○	○	○									
9										○	○	○	○	○	○	○	○
D1	○	○														○	○
D2	○																○

Switch D2 Automatically Selected

FIG. 3—SCHEME OF MAIN CONNECTIONS FOR SKIP HOIST

The master switch being located remote from the main controller and hoist apparatus makes it inconvenient to maneuver the hoisting machine when changing or adjusting cables. This objection was overcome by providing simple hand control in the hoist house, consisting of several small knife switches connected to the main controller. A single-pole, double-throw knife switch operates the reverse contactors; another single-pole, single-throw knife switch operates the accelerating switches, and another switch of the same type operates the slow-down contactors. This arrangement, in addition to convenience in maneuvering the hoist, permits, the electric repairmen to try out the main controller after any adjustments or repairs without being required to signal some person to operate the master switch. The scheme has the advantage over a duplicate master switch in that any operation of the main controller can be performed out of its regular order.

To prevent the car from approaching the stopping point at a dangerous speed, a relay is provided in circuit with the hoist armature and retarding resistance, that will operate to cut off power and apply the band brake should the circuit through the motor retarding resistance not be made at the proper time.

A blast furnace can produce continuously a certain amount of iron which has a certain value dependent upon market conditions. The maximum possible output under best possible conditions would ,while these conditions remain unchanged, result in 100 per cent output. Certain conditions arise, however, which require that the rates of melting be reduced and which results in loss of production commonly and erroneously termed delay.

A decrease in the rate of the melting process results not in delay of production but in curtailment of production and should be referred to as a loss in tons of iron or in units of monetary value and not as a delay in units of time. The same reasoning does not necessarily apply in departments using the product from a blast furnace.

In the case of an open hearth department depending entirely upon iron from the local blast furnaces, a shut-down is not necessarily a curtailment of production. As long as there is storage for the blast furnace production during a shut-down of the open hearth department and there is sufficient open hearth capacity to absorb the stored iron along with the normal output from the blast furnace, the stop could be properly termed a delay in production which would be regained later and would not necessarily represent a monetary loss in so far as production is concerned.

On the other hand, if there is always an abundant supply of iron and a demand for the open hearth product, a halt in operation in the open hearth department would be a curtailment of production and a monetary loss.

Therefore a failure of auxiliary equipment in any department beyond the blast furnace may result in a delay of production or a curtailment of production, dependent upon conditions. But a failure of auxiliary equipment of a blast furnace that causes a reduction of the melting rate is almost invariably a curtailment of production and a monetary loss that cannot be recovered.

Thus it follows that in selecting auxiliary equipment for a blast furnace the feature most desired is reliability. In selecting a skip hoist controller the requirements are in the following order:

1, Reliability; 2, maintenance; 3, depreciation; and 4, initial cost.

RELIABILITY

The detail parts of the controller should be as few as practicable in order to have a minimum number of possible sources of trouble. There should be enough switches to limit the accelerating current to a value that will not be harmful to the motor or other parts of the equipment. Four accelerating switches, thus giving five steps of acceleration, are ample.

Main contacts should be self-cleaning to prevent excessive arcing and freezing. Auxiliary contacts should be so designed as to prevent accumulation of insulating particles that may come from the atmosphere, or elsewhere.

Usually there is heavy electrically-driven machinery operating near blast furnaces that causes the line voltage to fluctuate widely, and shunt-wound switches, designed for 230 volts, particularly for skip hoist controllers, should be designed to operate successfully on any voltage between 175 and 260. The complete controller and its wiring should be so designed that a deposit of coke and ore dust that is common in the atmosphere about a blast furnace cannot cause grounds, short circuits, or sneak circuits.

Skip hoist controllers have in many cases been unnecessarily burdened with elaborate and complicated schemes for obtaining smooth, uniform acceleration, and cut-off point confined within very narrow limits. This is sometimes a very desirable accomplishment for a skip hoist controller to have, but the apparatus necessary for the accomplishment introduces complications and chances for trouble that very materially lessen the reliability of the controller, and the necessity for this close regulation should, whenever practicable, be avoided. A skip hoist controller with which the writer is familiar was originally designed with retarding resistance graduated in about 50 steps, which, by means of regulating apparatus, could be varied to keep the motor speed practically constant from no-load to full load (that is, empty car to load of ore or limestone), through the slow-down period which gave a minimum variation in the stopping point. It was found that a perfectly satisfactory slow-down effect could be obtained with the use of but two steps of retarding resistance. While regulation is not as close as with the original scheme, it answers all requirements and is very much more simple and reliable.

Since operating a skip hoist is only one of numerous duties devolving upon one man it is essential that the controller, after being started, perform all of its functions accurately, accelerating, retarding, and stopping automatically. All reasonable protection should be provided, including overload, no-voltage, open shunt field, slack cable cut-out, overspeed, overtravel, and provision to cut off power and apply the mechanical brake in case of failure to complete the circuit through the armature and slow-down resistance.

Resistors

The resistor to be used with a skip hoist controller is seldom given sufficient consideration, and for this reason it is very often a greater source of trouble than the controller, and invariably gives more trouble than it should. As the resistor has equal responsibility with the controller proper, and one is useless without the other, they should be given equal consideration. It is important that the resistor has sufficient carrying capacity to limit the temperature rise to 50 deg. cent. High temperatures will in time deteriorate any insulation now known to the art, and the result will be an ultimate breakdown.

Alternate heating and cooling of the resistor result in loose connections, fatigued material, oxidation, broken grids, open circuits, short circuits, grounds, etc. The more frequent the alternations and the wider the temperature range, the sooner will come one or the other of the above mentioned failures. Cast iron is not a desirable material for resistors because of its fragility. Mica is not a desirable insulation for resistors because of its mechanical weakness and rapid deterioration under certain conditions, such as heat, moisture, etc.

Another weakness in banks of cast grid resistors and one that gives more trouble than any other is the multitudinous number of joints, each grid being afflicted with from two or four joints, one on either side of the lugs.

WIRING

Too much emphasis cannot be placed on the importance of using the best materials and first class workmanship in installing the secondary wiring of the controller itself, and from the controller to the master switch, etc., particularly in connection with a skip hoist controller. For 250-volt work, wire made for 1500-volt working pressure should be used. Secondary wiring should be extra flexible and no wire smaller than No. 12 should be used. Care should be taken not to run wires connected to high resistance relay coils in the same conduit with wires subjected to high induced voltages, which may cause improper action of the relays.

MAINTENANCE AND DEPRECIATION

All parts that are subject to renewal should be easily accessible for inspection, repairs, and renewals. Spare parts should be as few as possible. This can be done by making all magnetic switches, all secondary contacts, etc., duplicate of each other. The terminals of all main and secondary wiring should be plainly marked and be so arranged to simplify tracing or testing in case of trouble.

A controller that is reliable and easily repaired and maintained will not be subject to depreciation; its life will be determined by obsolescence brought about by changed conditions. Unless there is a change in the design of the blast furnace or skip or some condition arises that renders the controller useless, it will give the same satisfactory service indefinitely.

COST

In selecting a controller for a blast furnace skip hoist, the purchase price should be the last consideration. A controller that would not be dependable seven days in every week should not be accepted as a gift, if one more dependable could be obtained.

HIGH-SPEED COAL HOIST

An outline diagram of a high-speed hoist, the control equipment of which will be considered, is shown in Fig. 4. This is a double hoist, each being capable of hoisting 100 tons of coal per hour, with a grab bucket of 70 cubic feet capacity, weighing 6200 pounds empty. The average weight of coal per lift is 1¼ tons, making a total average load of about 9000 pounds. Each hoist is driven by a 300-h-p., continuous rating, compound-wound 500-rev. per min., 230-volt, d.-c. motor, which is geared to a drum on which is the closing cable. To this drum through a solenoid-operated friction clutch is connected the shell cable drum.

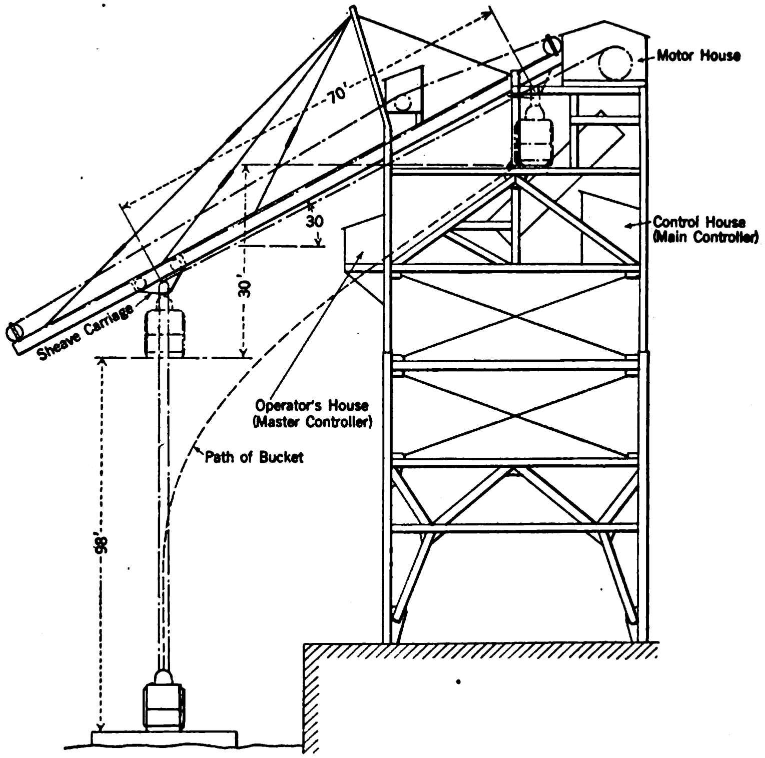


FIG. 4—COAL HOIST

The solenoid which operates the friction clutch is controlled by a push button switch in the handle of the operator's master controller. After the bucket is closed and the stress on cables is equalized, the friction clutch operates, connecting shell and closing cable drums together. While the bucket is being hoisted, the sheave carriage is moved by an auxiliary drive up an incline, the path of the bucket describing a parabolic curve, the total vertical lift being 128 feet.

When the bucket reaches the dumping point the friction clutch is released, a band brake, operated by foot lever, is applied to the shell drum, power is applied to the motor and closing cable drum in the reverse direction, and the coal is dumped into a chute and the bucket continues lowering and moving down the incline at the same time. The hoist motor is retarded by dynamic braking, with the shell and closing cable drums locked together and the bucket in the open position.

The actual time required to complete a round trip is 37 seconds. The permissible time per trip based on 100 tons of coal hoisted per hour and 1¼ tons per lift is 45 seconds. The power and time required for the complete cycle of operation is shown in Fig. 5.

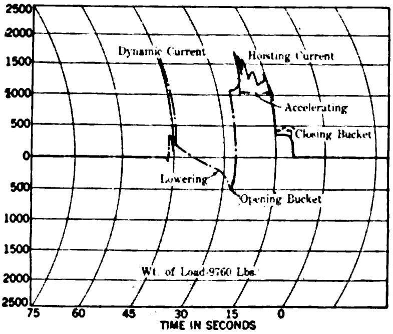


Fig. 5—Coal Hoist—One 300-h.p. Compound Motor, 220 Volts, 300 rev. per min., 1050 Amperes

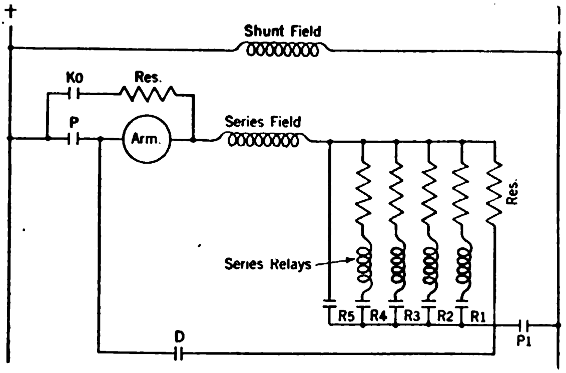
A simplified wiring diagram of the hoist motor and controller is shown in Fig. 6. The magnetic switches on this controller have a continuous rating of 1000 amperes and have given very satisfactory service for five years.

The Master controller, main controller, and motors are located as shown in Fig. 4. The resistor is located in an enclosure separate from the controller house.

On this kind of service it is important to keep all electrical equipment, particularly a magnetic controller, in an enclosure where it can be kept clean. Coal dust being a non-conductor will only be troublesome due to lodging on secondary contacts and insulating them, and by getting into moving parts of magnetic control apparatus; aside from this, it will do no particular damage except that precaution should be taken to prevent coal dust from accumulating in enclosures in which there is electrical apparatus, particularly in controller rooms, for the reason that arcing is liable to cause a conflagration of the dust.

Experiments that have been made by the U. S. Bureau of Mines have proved that less than 0.2 oz. of coal dust per cubic foot of air will, under favorable conditions, permit propagation of flame from particle to particle of dust and cause a conflagration that will produce a pressure in an enclosure, which will dislodge any dust that may be accumulated on the frame work of the enclosure, etc., and may cause an explosion with disastrous results. This feature should be kept in mind when installing electrical equipment of any kind about a coal hoisting or crushing plant.

Since an equipment of this kind requires an operator having at least the intellectual capacity of a street car motorman, elaborate protective features in connection with the control system are not needed. To devise a controller for an equipment of this kind that would be proof against a careless or incompetent operator would be impracticable if not impossible. The only protection necessary, as has been proved by five years' operation, is current-limit acceleration and overload protection.



Sequence of Switches

Sw.	Hoisting			Closing Bucket		Off	Opening Bucket	Lowering	Dynamic Stopping					
P	○	○	○	○	○									
R1	○	○	○	○	○					○	○	○	○	○
R2	○	○	○	○							○	○	○	○
R3	○	○	○									○	○	○
R4	○	○											○	○
R5	○													○
P1	○	○	○	○	○		○	○						
D						○	○	○	○	○	○	○	○	○
K0							○	○						

FIG. 6—SCHEME OF MAIN CONNECTIONS FOR COAL HOIST

As stated, there are two duplicate equipments on a common structure operating as one unit, hoisting coal from the same boat. To provide against heavy current surges on the transmission line and power plant, the hoist controllers were interlocked electrically to prevent both hoisting at the same time, but allowing one to hoist while the other is lowering. In addition to the benefits that were expected, this arrangement has resulted in lower maintenance cost on the hoisting plant, brought about by more even stresses on the structure, and a more even pace on the part of the operators, there being less tendency to reckless operation, since one operator cannot hurry unless the other operator does likewise, and one cannot slow down without affecting the other. The result is that capacity is maintained while stresses on the hoisting equipment and structure, transmission lines and power plant, are much less severe. This arrangement also permits of a more efficient use of the transmission copper.

Since an equipment of this kind must necessarily have some reserve capacity, there is usually sufficient time during the working turn to do all ordinary repair and maintenance work. We therefore attach less importance to continuity of operation for service of this kind, and give the matter of repair and maintenance cost, together with the initial cost, more consideration than if we were selecting a skip hoist controller.

The controller and its wiring, for service such as just described, should be easily accessible, simple in adjustment, and free from delicate refinements, so that the operator can make necessary adjustments and locate and correct all ordinary defects and failures in order that delay and expense of having to send for other more skilled help, be kept to a minimum.

The so-called series switch would not be suitable for this class of service for the reason that selective speed points are desirable both in hoisting and lowering.

Referring to Fig. 5, it will be noted that to accelerate, about 1400 amperes are required for a period of about 7.5 seconds, and only about 1100 amperes for three seconds are required after the accelerating resistance is all cut out until power is cut off. The accelerating resistance therefore is in circuit about 75 per cent of the total time that the motor is hoisting and it is in circuit about 20 per cent of the total times required for a complete operating cycle.

The accelerating resistance for this work should therefore have a capacity of 1000 amperes continuously with a temperature rise of 50 deg. cent. if it is to give satisfactory service. A resistor so designed would prevent excessive heating in normal operation and prevent burn-out in case of accelerating switches failing to close and leaving part of the resistance in circuit. With this rating, the saving in repairs and maintenance over a period of years would pay a handsome return on the additional investment necessary over what would be required for a resistor that would ordinarily be supplied for starting a 300 h.p., motor at full load on a 35-second operating cycle.

It would be conservative to say that no steel plant is free from trouble and expense incident to accelerating resistance of insufficient current carrying capacity, and that in a great many cases the repair and maintenance cost of the resistor alone, neglecting the expense and interruption to plant operation incident to resistor burnouts, etc., would justify the expense of replacing the troublesome resistor.

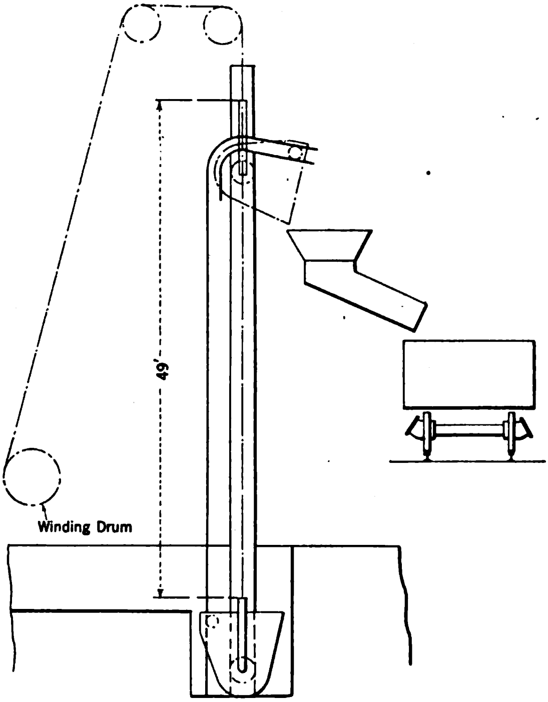


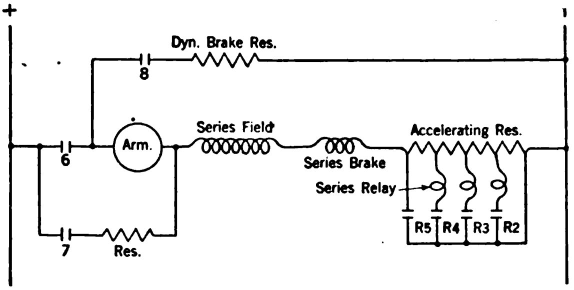
Fig. 7—Ash Hoist

Slow Speed Automatic Ash Hoist

The equipment to be considered here is used for hoisting ashes from a gas producer pit and dumping into a car on an elevated track, the general arrangement of the hoist being shown in Fig. 7.

The controller was designed to be operated by men who wheel ashes from the gas producer, it being only necessary for them to push a button and the bucket of ashes is hoisted and dumped and the bucket returned to the loading position without further attention. A simplified wiring diagram and sequence of switches are given in Fig. 8.

Without the automatic controller the man who would operate the hoist would have to be more skilled and be paid a higher wage rate than would a man who was only required to wheel ashes. This feature alone would justify the installation of the automatic controller. Then the possibility of an incapable operator damaging the hoisting apparatus is eliminated. The possibility of a properly designed automatic controller failing, and causing damage to the hoisting equipment, is very remote, as is evidenced by the record of failures referred to in our description of a blast furnace skip hoist automatic controller.



Sequence of Switches

Sw	S D	Up Accel.					Off	Down Accel.			
R2		O	O	O	O						
R3		O	O	O							
R4		O	O								
R5		O									
6	O	O	O	O	O	O					
7	O							O	O	O	O
8								O	O	O	O

FIG. 8—SCHEME OF MAIN CONNECTIONS FOR ASH HOIST

It will be noted in Fig. 9 that nearly double the time is required to lower that is required to hoist the bucket. The reason for this is that five minutes elapse from the time that the full bucket of ashes is started up until the man returns with a barrow of ashes for the next empty bucket. Advantage is taken of this time and the bucket is allowed to return all the way down on very low speed in order to reduce wear and tear on the apparatus and simplify the control.

The requirements of a controller for this service would be about similar to that of a blast furnace skip hoist controller in that it should have every protection to avoid damage to the hoisting equipment and that it should function positively and accurately. These features together with maintenance and initial cost should be given most consideration. Continuity of operation although desirable is not absolutely essential as is the case with a blast furnace skip hoist controller.

A controller for this service should be enclosed to prevent its being tampered with. All repairs and adjustments should be made by a competent electrical repairman.

The accelerating resistance should carry full load current continuously with normal temperature rise to avoid excessive heating in case that the accelerating switches fail to close and allow part of the resistance to remain in circuit.

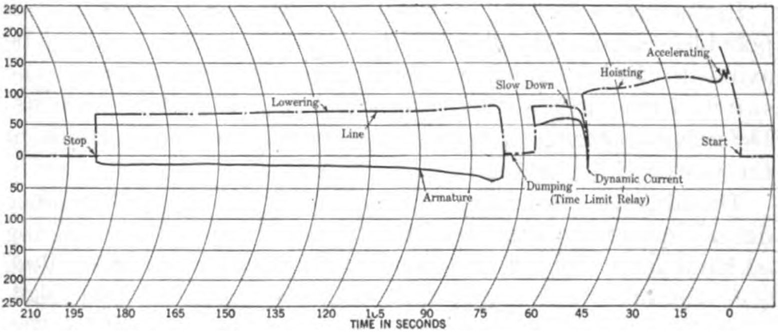


FIG. 9—ASH HOIST—ONE 25-H.P. COMPOUND-WOUND MOTOR, 550 REV. PER MIN., 250 VOLTS, 101 AMPERES

CONCLUSION

For applications similar to a blast furnace skip hoist where failure of auxiliary equipment is liable to cause a dead loss in production, the matter of reliability and continuity of operation is a necessity, in relation to which all other requirements are of secondary importance. The initial cost of a controller for this service should be a last consideration.

Where conditions are similar to those of the high-speed coal hoist that we have considered, where an ordinary delay does not effect plant operation and where the operator, since he must be skilled to a certain degree to operate the equipment, could also take care of all ordinary repairs and maintenance of the electrical equipment, the question of simplicity, repairs and maintenance, and initial cost should be given most consideration, the matter of continuity of operation while desirable is not a first consideration.

Applications similar to the slow-speed ash hoist which has been considered and which is to be operated by unskilled labor, require that the controller perform its functions positively and accurately, and have all protective features necessary to avoid damage in all cases to the apparatus which it controls.

Where the controller is designed for automatic acceleration, to provide against accelerating switches failing to close and leaving part of resistance in circuit and on manually-operated controllers where the accelerating period represents 10 per cent or more of the complete operating cycle, the resistor should have carrying capacity equal to that of its motor with a maximum temperature rise of 50 deg. cent.

Protective resistance in series with magnetic switches is a possible source of trouble which should, when practicable, be avoided. Failure to short-circuit the resistance prevents the switch from sealing thereby damaging the switch contacts. Defective resistance if not replaced immediately will result in the switch coil burning out.

The absence of any attempt at standardizing high-resistance units requires very careful attention to insure always having on hand spare units of the proper capacity and resistance value.

A simplified wiring diagram should be furnished with each controller. On the same sheet should be given all data necessary for obtaining spare parts; either catalogue reference or other means of identification.

Finally, in selecting a controller for a particular application all conditions must be considered, such as type of operator, conditions under which it will be located, operated and maintained, the relative importance of the different factors, such as reliability, simplicity, cost of repairs and maintenance and initial cost, the order of importance of which will be different for different applications.

A careful analysis of all of these factors will help to determine the best controller for the particular application and whether it should be non-automatic, semi-automatic, full automatic, or manually operated.

Generally speaking manually-operated controllers for service above 25 h.p. capacity should not be used on hoisting equipment.

An address presented at the 308*th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April* 15, 1915.

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(*Subject to final revision for the Transactions.*)

THE INDUSTRIAL POWER COMMITTEE

BY DAVID B. RUSHMORE

THE WORK of the American Institute of Electrical Engineers consists largely of the presentation and discussion of papers on:

1. New inventions and discoveries in the electrical field.
2. Compilation and review of the art in some particular line.
3. Description of installations.
4. Presentation of analytical studies of peculiar conditions and phenomena.
5. Subjects of general interest to electrical engineers.

The development of the electrical art has proceeded so rapidly that classification of the same in the Institute activities has not been made in all lines. The following outline prepared for use of the proposed International Electrical Congress is probably as good as any:

1. *Generation, Transmission and Distribution.* Central station and substation design, control and operation. Long-distance transmission of electric power.
2. *Apparatus Design.* Generators, motors and transformers. The rating of machinery.
3. *Electric Traction and Transportation.* City, surface and rapid-transit railways; interurban and trunk lines; electric vehicles, ship propulsion, mine railways, elevators and hoists.
4. *Electric Power for Industrial and Domestic Use.* Factories, mills, refrigeration, heating devices, etc.
5. *Lighting and Illumination.* Arc and incandescent lighting; the science and art of illumination.
6. *Protective Devices; Transients.* Switches, circuit breakers; condensers; electrostatics; disruptive phenomena; high-frequency phenomena.
7. *Electrochemistry and Electrometallurgy.* Electrolytic and metallurgical apparatus and processes.
8. *Telegraphy and Telephony.* (a) All communication of in-

telligence by the use of wires. (b) Electromagnetic waves and radio-telegraphy and telephony.

9. *Electrical Instruments and Electrical Measurements.* Switchboard, portable, standard and absolute instruments. Testing and standardization methods; absolute measurements.

10. *Central Station Economics.* Load factors, power factors, measurement of maximum demand and all problems affecting the economy of central stations; also rates, their regulation and legislation.

11. *Electrophysics.* Radioactivity; Röntgen rays; gas and vapor conduction; electron theory; constitution of matter, etc.

12. *Miscellaneous.* Such as history and literature of electrical engineering; symbols and nomenclature; engineering education and ethics.

As the activities in different lines have increased, technical committees have been appointed in the Institute to provide fields for the presentation and discussion of engineering papers on these different subjects. In some cases where the Institute has not provided this opportunity in time, separate organizations outside of it have been formed, and the number of these has now reached the point where the matter is deserving of very serious consideration. The multiplicity of organizations, with their proceedings and conventions, is involving the various memberships in such a considerable expense in time and money that any improvement in efficiency in co-ordinating such functions will be very warmly welcomed.

There is no field of activity in electrical work at the present time more important than that concerning the use of electric power in manufacturing industries. The rapid growth of this field and the wonderful possibilities for future development make it of great importance and interest to the consulting engineer, to the electrical manufacturer, and to the power companies, as well as to the industrial organizations themselves.

It is the object of the Industrial Power Committee to provide opportunity for such engineering activities in this field as is demanded by the situation, and by the desires of electrical engineers engaged in this work. That such a demand can be, at best, only supplied in part is self-evident.

Industrial power work from an engineering standpoint consists largely in the application of electric motors, controllers and auxiliary apparatus to the driving of the various machines which are used in the different industries, and involved in this, of course, are the many questions concerning the supply of power.

The engineering work of the Industrial Power Committee may be divided into four more or less distinct parts.

1. Electric motors.
2. Controllers and auxiliary devices.
3. Conditions involved in motor application.
4. The application of electric motors to manufacturing processes.

A presentation of the subject of "electric motors" was made at the session the Midwinter Convention in New York in February; the subject of "conditions involved in motor application" was treated at the Cleveland Meeting; the subject of "controllers and auxiliary devices" is to be discussed at Pittsburgh, and a topical discussion on "the application of electric motors to manufacturing processes" is to be held at the Annual Convention in June.

Engineering work, properly understood, must have some direct relation with commercial activity, and the Industrial Power Committee desires to have its work of such a nature as to be of direct assistance to the various operating and commercial organizations who look to the Institute for the source of their engineering information. Such a development is, naturally, in process of growth and far from being in any final or complete form.

An attempt is being made during the present year to bring before the Institute, in the form of papers and discussions, a more or less complete survey of the present state of the art of motor application, and, like all first attempts, this must necessarily be somewhat imperfect and incomplete, and yet it is a beginning in a line of development which should become of very great value.

In addition, the Industrial Power Committee is arranging a series of lectures composed of lantern slides with a type-written copy of the lecture, to be kept at Institute headquarters in New York and to be available for any of the Institute Sections and Branches desiring the same.

It is hoped that future construction on this foundation will be along the line of an annual report by the Committee which would cover this subject more thoroughly and completely than can be done by papers and discussions, such reports to be in the nature of an engineering handbook on the subject and to furnish such technical information as can be used, by those interested in the subject, as the foundation for developments in practical lines by the power companies, by the manufacturers and the various interested engineers, as well as a text book for use in educational institutions. Such a handbook, revised as occasion may require and kept up to date, would be a very valuable contribution by the Institute to the industry, and would be contributing in a very proper way to its function as an engineering society. It is with the object of laying the foundation for such work that the program for this year was laid out.

In the discussions at the meetings under the auspices of the Industrial Power Committee it is desired to have the result of experience presented as clearly and as forcibly as possible, and also to have divergent points of view brought out in such a way as to contribute to the understanding of the subject. This means that differences of opinion when properly expressed are highly desirable, and that cooperation between men engaged in various parts of this activity, in pooling their various and probably different points of view, is one of the desirable results.

The technical committees of the Institute at the present time have a very fitful and uneven activity and are probably but the forerunners of a future form of organization which will meet the natural demands of the membership as the future growth of the art and of the Institute necessitates. It must of course be the primary object of the membership of such a committee to supply such requirements and to assist in such progressive activity as conditions may justify.

The work which is being done by the Industrial Power Committee this year will, it is hoped, be but the foundation of a continued activity in the future which will finally develop material in such concrete form as will be of the most useful assistance to the profession and to the whole electrical and manufacturing industry.

Presented at the 308*th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April* 15, 1915.

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STEEL MILL CONTROLLERS FROM THE OPERATOR'S STANDPOINT

BY J. S. RIGGS

ABSTRACT OF PAPER

The writer discusses control problems from the operator's standpoint, in connection with bloom mill and rolling mill machinery. The most important consideration is that no provision for emergencies can be allowed, and when the ingot or bloom leaves the furnaces for the rolls it must be kept moving until it reaches the cooling beds. Any interruption in this cycle means scrap material and lost time. To fulfill these requirements the equipment must always stand up to the service and be as nearly fool-proof as possible. The full magnetic controller in the writer's opinion meets the above requirements better than any other type.

The requirements of the different classes of machinery are tabulated and from this tabulation it is shown that the control can be standardized in four distinct types one or the other of which will meet all conditions of mill equipment: 1. Full reverse single-speed type. 2. Full reverse multi-speed type. 2-a. Full reverse multi-speed type with dynamic braking. 3. Non-reverse push-button type.

In conclusion the author points out that the conditions to be met and their solution should be kept as uniform as possible and the aim should be towards simplicity. The expense of duplication would be avoided by standardization of parts, and this would also permit comparison of different makes of apparatus on an equal basis.

THE PURPOSE of this paper is to describe the forms of electrical control peculiar to steel mill service, "from the operator's standpoint." It is possible and probably usual to treat the subject by averages, to make statements as the result of many opinions. In this paper the other general procedure will be followed in that the ideas are as the writer sees them. This plan has been adhered to purposely. I do not expect complete agreement. I do hope this method will provoke constructive criticism, all to the end of definite recommendation, if such be possible, toward uniformity of attack to meet the given condition.

The steel mill is distinct in many ways from any other manufacturing industry and one of the most important of these dis-

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tinctions is that no provision for emergencies can be made; that is, when an ingot, bloom or billet leaves the furnace for the rolls it has to be kept moving until it reaches the cooling beds. Any delay or interruption in this cycle means scrap material and loss of time.

Considering the above service requirements and operating conditions, the equipment must stand up to the service, and be as nearly fool-proof as it can possibly be made. The full magnetic controller, in my opinion, meets the above requirement better than any other type, and also has several additional advantages which may be briefly enumerated as follows:

1. Superior ability to handle heavy currents at a minimum of maintenance cost and delays.
2. Inherent current-limit acceleration feature. Taking acceleration entirely away from the operator.
3. Can be operated by a small master controller which is easy to handle thus eliminating the element of fatigue of operator.
4. Limit switches and automatic cut-out switches can be applied in any position so that "slow-down" dynamic brake stop, as well as any other automatic feature required can be obtained.
5. Complete remote-control circuit breaker protection at a very slight additional cost.
6. "Safety first"—Removes all arcs from immediate vicinity of operators. In fact, with magnetic control, the operator is insulated from all live parts.

In order to bring out clearly the different equipments with their control in, for example, a bloom mill and a rolling mill, the following outline sketches and tables may be of assistance.

The control for the following outlined equipment, which covers practically typical mill equipments, can be standardized in four distinct constructions, as follows:

1. Full reverse, single-speed type.
2. Full reverse, multi-speed type.

2a. Full reverse, multi-speed type, dynamic braking.

3. Non-reverse, push-button type.

(1) The full reverse, single-speed type, should contain the following apparatus.

4 Reverse switches, mechanically interlocked.
3 or 4 accelerating series or lock-out switches.
Three switches up to 75 h.p.; above 75 to 200 h.p., four switches.
1 Main line contactor.

2 Overload double-coil relays.
1 Main line switch, double-pole, single-throw, safety type.
1 Control switch, double-pole, single-throw, and fuses.
1 Terminal board.
1 Angle iron or pipe frame.
1 Resistance, to be mounted on rear of frame below panels.
1 Single speed master radial arm type with overload reset in off position.

This controller will take care of at least 50 per cent of mill work and can be used on the following equipment.

A. All roller tables.
B. Screw-downs.
C. Rollers on tilting table.
D. Soaking pit covers.

Limits can be used with this control in any place where conditions may require them.

(2) and (2a) Full reverse, multi-speed type, should contain the following apparatus.

4 Reverse switches, with mechanical interlocks.
4 or 5 accelerating switches, shunt type series accelerating relays. Four switches up to 75 h.p.; above 75 to 200 h.p., five switches.
1 Main line contactor.
1 Dynamic brake switch.
2 Overload double-coil relays.
1 Main line knife switch, double-pole, single-throw, safety type.
1 Control switch, double-pole, single-throw, and fuses.
1 Terminal board.
1 Angle iron or pipe frame.
1 Resistance to be mounted on rear of frame below panel.
1 Multi-speed master radial arm type with overload reset in off position.

This type of controller can be used wherever conditions are such that a single-speed equipment, even with the plugging feature, will not meet them. For instance, this type of controller should be used where varying loads obtain, where refinement of control is required, where dynamic braking or slow-down features are desired, and can be used on the following equipment.

A. Kick-off.
B. Dogs or drags on transfer tables, hot-bed, etc.
C. Furnace pushers.
D. Tilting tables.
 Hoist-lowering.
E. Hot metal mixers.
F. Open hearth floor type charger, bridge, hoist, trolley and reel.

No	Equipment Operated.	Type Contr.	Reverse Non-rev	Type Master	Limits	Special Features.
	Bloom Mill.					
1	Soaking Pit Covers	Magnetic	Full rev	1-Speed.	2-Way.	....
2	Ingot Del. Table	"	" "	"	....	....
3	Mill Appr. Table	"	" "	"	....	....
4	Mill Rev. Table	"	" "	"	....	....
5	Two-High Mill. A-Screw-down	"	" "	"	....	....
6	Mill Rev. Table	"	" "	"	....	....
7	Shear Appr. Table	"	" "	"	....	....
8	Shear	"	Non rev	Push button	....	....
9	Shear Del. Table	"	Full rev	1-speed.	....	....
	A-Kick-off.	"	" "	Multi. "	2-way.	slow down
10	Hot-Bed. A-Drags or Dogs	"	" "	"	....	"
	Rolling Mill.					
1	Furnace Pusher	"	" "	"	"	" "
2	Furnace Feed Tables	"	" "	1-speed.	....	....
3	Furnaces	"	....	....	....	....
4	Furnace Discharge Table	"	" "	1-speed.	....	.....
5	Tilting Tables					
	A-Bridge	"	" "	Multi "	....	....
	B-Hoist	"	" "	" "	2-way.	Dyn. brake Lowering
	C-Rollers	"	" "	1-speed.	....	
6	Three High Rolls	....	...	....	....	....
7	Tilting Tables. Same as 5					
8	Hot Saw Appr. Table	Magnetic	Full rev	1-speed.	....	....
9	Hot-Saw	"	Non-Rev.	Push-button.	....	....
	A-Hot-Saw Feed	"	Full rev	Multi-spd.	2-way.	Auto. feed depending on cut.
10	Hot-Saw Del. Table	"	" "	1-speed.	....	....
	A-Hot-Saw kick off	"	" "	Multi-spd.	2-way.	slow down
11	Hot-Bed.					
	A-Hot-Bed Tipper	"	" "	" "	"	" "
	B-Hot-Bed Drags	"	" "	Multi-spd.	"	" "
12	Straightener Appr. Table	"	" "	1-speed.	....	....
13	Straightener	"	Non. rev.	Push-button	....	Field control. Vibrating field relay.
14	Shear Appr. Table	Magnetic	Full rev	1 speed.	....	....
15	Shear.	"	Non-Rev.	Push-button	....	....
16	Shear Dis. Table	"	Full rev	1-speed.	....	....
	A-" " " Kick-off	"	" "	Multi-spd.	2-way.	slow down
	B-Transfer Dogs	"	" "	" "	"	" "
17	Cold Saw Appr. Table	"	" "	1-speed.	....	....
18	Cold Saw	"	Non-rev.	Push-button	....	....
	A-Cold Saw Feed	"	Full rev	Multi-spd.	2-way.	auto. feed depending on cut.
19	Cold Saw Dis. Table	"	" "	1-speed.	....	....

This type of control without the dynamic brake feature is also suitable for the following:

G. Tilting furnaces.

H. Tilting table bridge.

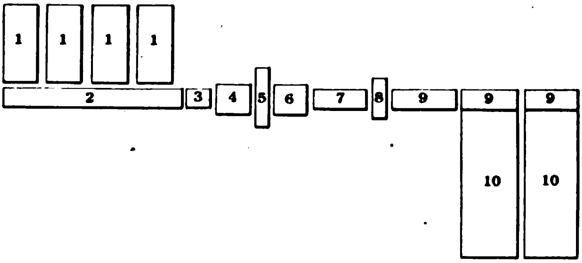

FIG. 1—BLOOM MILL

1. Soaking pit
   A. Soaking pit covers
2. Ingot delivery
3. Mill approach table
4. Mill reversing table
5. Two high mill
   A. Screw-down
6. Same as 4
7. Shear approach table
8. Shear
9. Shear delivery tables
   A. Kick-off
10. Hot-bed
    A. Hot-bed drags

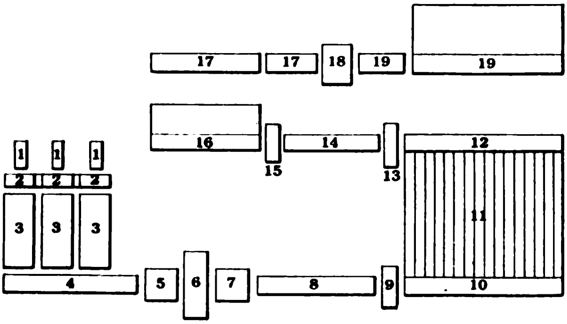

FIG. 2—ROLLING MILL

1. Furnace pushers
2. Furnace feed roller tables
3. Furnaces
4. Furnace discharge roll table
5. Tilting table
   A. Bridge
   B. Hoist
   C. Rollers
6. Rolls
7. Same as 5
8. Hot-saw approach table
9. Hot-saw
10. Hot-saw delivery table
    A. Hot-saw delivery table kick-off
11. Hot bed
    A. Hot-bed tipper
    B. Hot-bed drags
12. Straightener approach table
13. Straightener
14. Shear approach table
15. Shear
16. Shear discharge table
    A. Shear discharge table kick-off
17. Cold saw approach table
18. Cold saw
19. Cold saw discharge table

The question may arise as to the extent to which line protection devices shall be employed. A reversing controller in its simplest form does not provide for the disconnecting of the series field of the motor from one side of the line. This is not such an important detail so long as the controller is not provided with overload relays, but if overload relays are installed and the contactors which are used for reversing the armature and to open and close main line circuit, are depended upon to afford line protection in combination with overload relay or relays, a condition may arise in which the motor field will be grounded and the reversing switches will be powerless to disconnect the grounded field winding from the line.

Moreover, certain combinations of grounds, in case but one overload relay and no extra main line contacts are used, may result in short circuiting that relay and the consequent loss of overload protection without such condition coming to the attention of either the operator or the motor inspector.

The only way absolutely to protect the equipment against short circuits and overloads is to install two relays, one in each side of the line and also install a contactor in that side of the line which feeds the motor field winding, which arrangement gives the most complete protection possible to obtain.

Each control panel should also include a main line knife switch for the motor circuit, this knife switch to be so equipped that it may be locked open by safety pad-locks, thus protecting men working on the control equipment or the associated machinery.

Each control panel should include a control circuit knife switch, and fuses for protecting the control circuit, as it is obvious that if the overload relay on the panel is set high enough to protect the motor, a very destructive short circuit may occur in the control system, without taking sufficient current to trip the main overload relay. The fuses guard against this contingency and make it possible to connect the control circuit outside the main line knife switch so that whenever the motor inspector desires to test out the control system, he may pull the main line knife switch and operate all contactors without running the motor.

(3) The non-reverse, push-button type should include the following apparatus.

1 Main line contactor.
3 or 4 accelerating switches, series or lock-out type.
    Three switches up to 50 h.p.; four switches from 50 to 200 h.p.
    The last accelerating switch to hold in on zero current.
1 Overload double-coil relay.
1 Main line double-pole, single-throw, knife switch and fuses.
1 Terminal board.

1 Shunt field protecting relay. Not considered necessary below 30 h.p.
1 Angle iron or pipe frame.
1 Resistor mounted on rear of frame.
1 Push button " start," " stop" and " reset."

Additional to above where variable speed is required, as for instance on straighteners—

1 Vibrating field relay.
1 Field rheostat.

The above type of controller without the additional features can be used on

A. Furnace fans.
B. Shears.
C. Cold saws.
D. Hot saws.

In fact, this type of controller is suitable for the majority of constant-speed mill equipments.

I have not attempted to give horse powers for any of the equipment mentioned because of the wide range and the power required by mills, due to different size mills and local conditions, but it would be my recommendations in laying out a mill to keep to as few different sizes of motors as possible throughout. This will not only keep down motor spare parts but will cut down to a minimum the number of sizes of controllers required, and in this way cut down the total amount of spare parts required for permanent stock.

I would recommend control panels being made up of an assembly of slates containing the various pieces of apparatus which go to make up the controllers.

I will touch briefly on a few points which I think would help the operator. If there were some standardization so that he could compare different makes of apparatus on an equal basis, these items will be of assistance.

(1) Contactors.
    Area of contacts.
    Pressure between contacts.
    Rating per unit area of contact.
(2) Resistors.
    Standard ratings.
    Cross section.
    Contact area.
    Spacing.
    Type.

Contactor coils should be interchangeable on the same size apparatus of one manufacturer. Use external resistance when coils have to stand continuous service rather than a special coil.

In conclusion the point attempted at the introduction is emphasized. Make the conditions to be met as uniform as possible. Solve these both from the manufacturing and the operating standpoints by uniform methods. Strive for simplicity. Save the expense of duplication. These, I believe, to be engineering fundamentals peculiar to the subject.

Presented at the 308*th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April* 16, 1915.

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CONTROL OF DIRECT CURRENT HOISTS IN IRON AND STEEL MILLS

BY G. E. STOLTZ AND W. O. LUM

Abstract of Paper

The control problem discussed in this paper is confined entirely to a typical example of a skip hoist. An outline of the conditions existing in the case of this particular application is given in which the load on the hoist is divided into three parts, namely, the friction load, the inertia of moving parts, and the useful work in hoisting the net load. The proper cycle of operations is determined, which in turn determines the required characteristics for the motor and controller which are together considered as a unit. The details of this d-c. skip hoist control are described and illustrated.

THIS SUBJECT would, in general, confine our discussion to skip hoists, cranes and ore handling machinery, the operation of each being sufficiently different from the others to warrant individual consideration. To treat each of these applications properly would require too much time, so it has been decided to confine our discussion to a typical example of a skip hoist.

In order to design control apparatus intelligently for an application of this kind, it is necessary for the engineer to understand fully the function of the various parts of the driven apparatus as well as the operating characteristics of the electrical machinery. We will therefore outline the existing conditions of this particular application, and then suggest a control which seems best to meet the definite requirements set forth.

Skip Hoists

Fig. 1 is an illustration of a typical hoist which has been selected for consideration in this paper. The load on a skip hoist can be divided into three parts, namely, friction load, inertia of the moving parts, and useful work in hoisting the net load.

The static friction at the moment of starting is, of course,

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greater than the running friction, but it is a comparatively small item, and with the machine in approximately continuous operation the static friction is not excessive, so that it is ordinary practise not to differentiate between static and running friction in calculating the load cycle. No formula can be used to determine definitely the friction, but various empirical rules are employed which approximate the true values sufficiently close to that obtained on hoists under normal operating conditions.

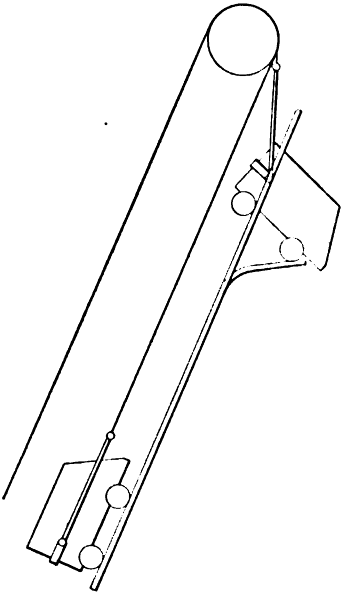


Fig. 1—Sketch of Typical Skip Hoist

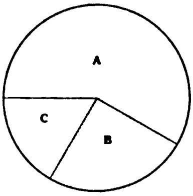


Fig. 2—Chart Showing Relative Inertia Values of Moving Parts

A—Motor armature
B—Drums
C—Cars and ropes

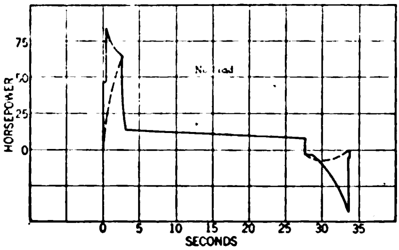


Fig. 3

The next item involved is the inertia of the moving parts. The apparatus involved consists of the drums, sheaves, gearing, armature, ropes, skips, and net load. The energy required to overcome the inertia of a moving body varies directly as its weight and as the square of its velocity. Therefore to minimize the starting and braking peaks, care should be exercised in the design of the apparatus. The diameter of the rotating parts should be kept as small as possible consistent with good mechanical design, as the velocity of these parts is a direct function of the diameter. This feature is characteristic of reversing mill motors, which are designed long and small in diameter to reduce their flywheel effect.

The weight of the armature is comparatively small, but its high velocity makes it an important item as is indicated in Fig. 2.

The skip will occasionally be operated empty, the cycle being approximately as indicated in Fig. 3. The normal operation of this particular skip is two loads of coke, net weight 3000 lb. each, two loads of limestone, 3000 lb. each, two more of coke and four loads of ore, 6000 lb. each. This cycle will be varied to obtain satisfactory distribution of the material in the furnace, but is sufficiently near the average operating conditions for our purpose. Occasionally a load of scrap weighing 9000 lb. will be hoisted, but this is rare and need not be taken into consideration except as an overload for a few seconds. Fig. 4 graphically illustrates the load cycle when hoisting a 3000-lb. load. The curve is plotted between time, expressed in seconds, and torque expressed in equivalent horse power. During the accelerating period the dash line *AB* represents the actual mechanical output of the motor, but, since we are interested in the current taken from the line, all energy values will be expressed in the horse power equivalent of torque. The area enclosed in the triangle *ABC* represents the energy dissipated in the starting resistors during the accelerating period. This is one-half of the total input while coming up to full speed, as indicated in Fig. 5.

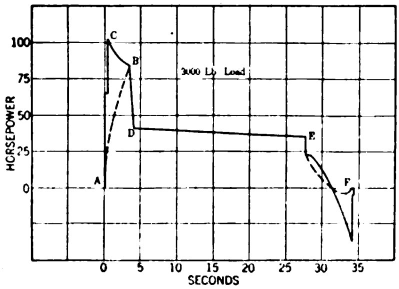


FIG. 4

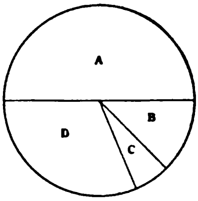


FIG. 5—CHART SHOWING DISTRIBUTION OF ENERGY WHEN ACCELERATING 3000 LB. LOAD
A—Rheostatic loss C—Friction
B—Inertia D—Useful work

It will be noted in Fig. 4 that the initial peak is only 66 h.p., whereas we would naturally expect it to be 105 h.p. This is the result of lifting the top skip off its track.

Before dynamic braking was introduced, with magnetic control, it was necessary to lift the skip two to four inches off the track when hoisting light loads to make sure the heavy loads would rise to a sufficient height to dump. At present dynamic braking can be made severe enough to practically stop all loads at one position. There is nothing to gain by doing this, and the rope is therefore adjusted normally to lift the top car off the track a few inches. This utilizes the whole car as a counterbalance and helps to land the skips more carefully. When the cars are again started the top skip still acts to its full capacity as a counterbalance and reduces the initial current peak accordingly.

On a vertical hoist the line *CB* would be straight, the difference in height of the two points being due to the transfer of the weight of the rope from the load to the counterbalance side of the hoist. During the acceleration period the top car comes down over the knuckle, which changes its effect as a counterbalance, and accounts for the shape of the curve *CB*.

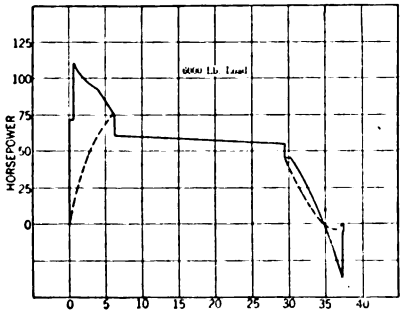


FIG. 6

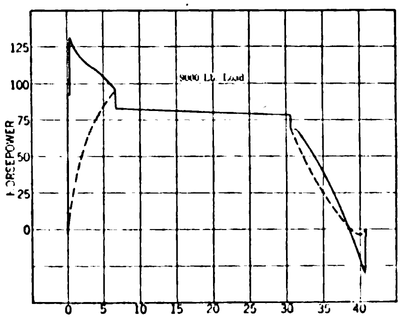


FIG. 7

The line *DE* represents the load when hoisting at constant speed. As the loaded car rises and the empty skip lowers, the net weight of the rope gradually favors the counter-balance and decreases the energy taken from the line.

During the period *EF* it is proposed to operate the control to obtain a gradual slow-down. When the loaded car goes up over the knuckle and starts to dump very little energy is required to continue its travel, as indicated by the shape of the slow-down curve. During this period we have friction and net weight acting against the inertia of all moving parts. If the latter is not sufficient to carry the car to its destination the motor will take energy from the line. Just before the cars reach their final position, dynamic braking should be introduced to bring the apparatus to a stop, at which time the line switches should be opened and the holding brake applied.

Fig. 6 represents the 6000-lb. ore load, and Fig. 7 the occasional 9000-lb. scrap load. Both are developed in the same manner as Fig. 4. The time of acceleration increases with the load, as the series switches will not operate so rapidly as with light load.

The interval of time between hoisting varies considerably, but the capacity of the control installed is determined by the maximum demand which generally occurs after a breakdown. If the skip is not in operation for a period of time, the burden in the furnace may become so low that two or three hours are required to bring the furnace back to its normal condition. The rating of the control should therefore be based on the regular cycle of hoisting the 3000-lb. and 6000-lb. loads with an average interval between trips of eight seconds. The apparatus will then be somewhat liberal for ordinary operating conditions, but this is a point which should be received with favor, as low maintenance and continuity of operation are important in an application of this type.

The root-mean-square current will determine the carrying capacity of the switches with reference to heating. For the different loads these values, as well as the maximum values, are as follows:

	R. M. S.		Maximum	
Load	H.P.	Current	H.P.	Current
9000	76	300	128	500
6000	57	240	110	430
3000	42	182	102	400
Friction	24	116	83	334

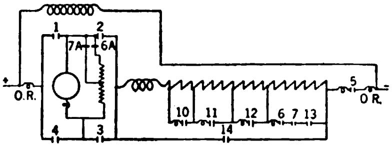
The average heating current taken from the line during the heaviest cycle of hoisting the 3000-lb. and 6000-lb. loads is 210 amperes, and the maximum is 430 amperes. The accelerating switches can open immediately after the last switch is closed so that they only need to carry an average current of 380 amperes, for a short time during each cycle.

The slow-down switches should be designed to handle the current adequately during this period of the cycle. The values actually obtained depend somewhat on the method employed of bringing the apparatus to rest.

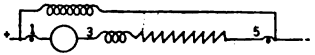
Resistance will be required during the starting and retarding periods. An average of 220 h.p-sec. must be absorbed during the starting period of each cycle, and 600 h.p-sec. when retarding.

Fig. 8 shows a sequence of control, starting at rest and accelerating the motor to full speed, then the slow-down and stopping of the load.

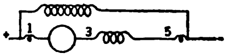
The acceleration of the motor is controlled by a current-limiting device. For this reason the amount of current taken by the motor on the first notch must be sufficient always to start the motor with the maximum load of 9000 lb. This means that the starting current should be something more than the value required to start the load under ordinary conditions, so as to take care of tight bearings and other variations in the load.



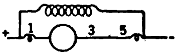
Off Position



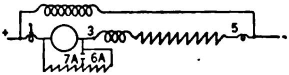
First Step Starting-All Res. In.



All Res. cut out Step by Step



All Res. and Series Field Short Circuited



1st. Slow-Down
2nd. Slow-Down with less Shunt Res.
Off Position leaves Dyn. Brake on Motor

FIG. 8

The number of accelerating points that is required will be determined by the maximum current peaks permissible. The number will also depend upon the characteristics of the particular motor used. It has been found in practise that six accelerating switches usually give satisfactory results on hoists of this character, with motors of 100 to 200 h.p.

Series-wound switches may be used for all but the last accelerating notch. This last notch should be a shunt switch or its equivalent. This switch is used for short circuiting the series field of the motor, and it is very important that the switch remain closed after the motor has been brought up to full speed. There are conditions of operation which may cause the motor to regenerate, which will reverse the current and cause the series switch to open.

After the skip has reached full speed and approaches the end of its travel, the motor must be slowed down in order to make an accurate stop. The diagram shows the slow-down is effected by connecting a resistance in shunt with the armature of the motor and opening all of the accelerating switches, which inserts the series field and starting resistance between the motor and the line. The second slow-down step consists in reducing

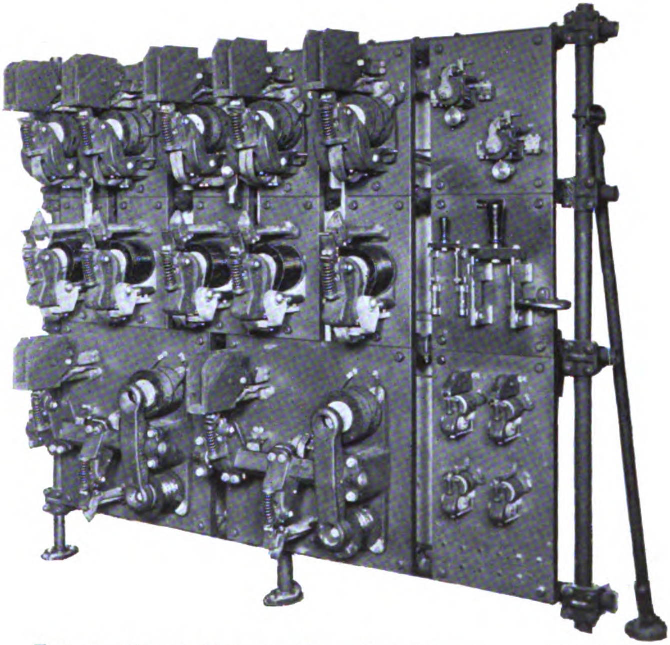


FIG. 9—FRONT VIEW OF SKIP HOIST PANEL [STOLTZ AND LUM]

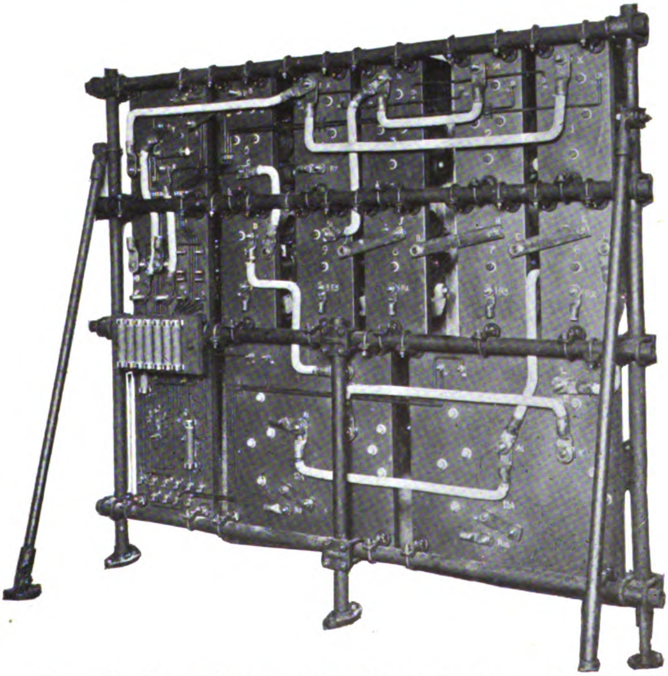


FIG. 10—REAR VIEW OF SKIP HOIST PANEL [STOLTZ AND LUM]

the resistance in shunt with the armature. This shunt resistance causes a definite current to flow through the starting resistance and series field of the motor. This shunt current is independent of the load and the current taken by the motor, so that a low voltage is impressed across the motor terminals. This slow-down should exist for a period long enough to enable the motor to reach a constant speed before it is finally stopped. The motor is stopped and the mechanical brake applied when the line switch is opened; the resistance is maintained across the motor armature and the shunt field is energized so that a dynamic brake is obtained in addition to the mechanical brake. The acceleration and slow-down are obtained automatically by means of proper switches attached to the hoist mechanism. The motor, however, can be controlled entirely from the master switch when desired. If the skip hoist should fail for any prolonged period, while the furnace is in service it will result in serious damage, and for that reason every precaution should be taken to prevent a failure with the electrical equipment. The master controller and limit switches should open both sides of all coil circuits and the shunt brake circuit, so that a ground or other disturbance on the control wire will not prevent the motor being brought to rest.

In equipping the skip hoist, or for other applications where it is necessary to perform a definite cycle of operations and insure the customer against failure, it is very necessary to consider the motor and controller as a unit. The amount and kind of material forming the magnetic circuit of the motor will introduce a time element. The design of the motor itself may fit the amount of current used during different parts of the cycle. The function of the controller is solely that of furnishing the motor with the assistance the motor requires in going through its cycle of operation. As the design of the motor is improved, some of the functions of the controller may be incorporated in the motor, and the controller simplified. In slowing down and stopping the motor, most of the stored energy is in the armature of the motor. This item must be considered carefully so that the design will give a positive and accurate stop without imposing too great a strain upon the brake.

Presented at the 308th meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 16, 1915.

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ALTERNATING-CURRENT CONTROLLERS FOR STEEL MILLS

BY ARTHUR SIMON

Abstract of Paper

The induction motor with either squirrel cage or wound rotor is practically the only type of alternating current motor used for general industrial purposes in this country and therefore the author has confined his paper to considerations of the control problems offered by induction machines. The various types of alternating current controller in use are described and illustrated and the advantages and disadvantages of each type as well as its limiting capacities are discussed. A number of typical examples of installations of alternating-current controllers in mill work and allied industries is described.

THE APPLICATION of electric drive in the steel mill and allied industries is beyond the experimental stage, and there cannot be today any more question regarding the general advisability of using the electric motor. The earlier development, however, made use of the direct-current motor almost exclusively, and alternating-current motors have been introduced into the industry on a larger scale only during the last few years. A great many different types of controllers for alternating-current motors have been developed, but their suitability for all classes of work has scarcely been discussed at any of the meetings of the technical societies dealing with these subjects.

From the standpoint of speed control and torque characteristics, as well as in regard to the ease of control for practically all applications, the direct-current motor has proved almost ideal, and it would have remained alone in the field had not the tremendous expansion of the industry required a more efficient power transmission system than is possible with direct current. After high-voltage alternating current had been introduced for the transmission of energy over larger areas and long distances, it was, of course, considered advisable to use the alternating-current motor direct instead of installing translating devices to obtain direct current for the motor drive.

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There are on the market at the present time two principal types of alternating-current motors, which are quite distinct in their characteristics—the commutator type motor and the induction motor. Little need to be said about the commutator type motor, because its practical development has been seriously delayed in this country and with a few exceptions, the lines which have been developed are of small capacity, and, therefore, do not offer any great problems to the designer of controllers. It would seem, however, desirable to the writer that the development of the commutator type motor for industrial purposes should be accelerated in this country, following the lead of Europe, where such commutator type motors are employed on a larger scale and with as much success as can be expected from a new machine.

In this paper we deal with American conditions, and we can restrict our considerations to the controller problems offered by the induction machine. The induction machine is built with either a squirrel-cage or a wound-rotor type of armature. The former may be used for constant-speed work and the latter for either constant or varying speed work, but neither one is adaptable for adjustable speed work.

The squirrel-cage motor on account of its simplicity, the absence of a collector, and its staunchness, is the most desirable machine for steel mill service. Its disadvantages are usually a low starting torque and a high starting current. It can not therefore, be employed where heavy starting friction has to be overcome, and it is, of course, not suitable for the frequent reversal and acceleration of heavy masses. The slip-ring type motor, on the other hand, does not have these disadvantages, but it requires a collector which is the cause of frequent trouble. On account of the necessity of short circuiting the armature over the slip-rings, brushes and some external connections, the rotor losses are greater than they are in an equivalent squirrel-cage machine, and the efficiency of the slip-ring motor is therefore somewhat lower. In very large systems, the voltage in the armature is relatively high, in order to reduce the current to a reasonable value, and this leads to insulation troubles on the slip rings.

The question of control must also take into consideration purely commercial points. We must weigh the relative advantages of low first cost, power consumption, labor and attendance and the renewals. The effects of these different points are more or less contradictory to each other, and they, therefore, have to be weighed carefully before deciding upon a particular type of motor and controller.

All types of controllers may be divided into two classes; hand and automatic controllers. There is no strict dividing line between the two classes, as there are a great many devices in which some functions are performed manually and other functions of the same controller are automatic. We therefore speak of semi-automatic controllers, which take a position halfway between the manual and the automatic devices.

From the standpoint of first cost, the hand controller is usually the cheapest, but, on the other hand, the cost of attendance for its operation, the usually increased power consumption due to improper operation and the cost of renewal, due to unwise handling of the controller, may be more than sufficient to counterbalance the increased cost of a full automatic controller for the same work.

FACE-PLATE TYPE CONTROLLERS

The simplest and earliest type of controllers are of the face-plate type. These controllers are used in connection with squirrel cage motors for the control of resistance in series with the primary circuit, and with slip ring type motors, in which case they are usually arranged to handle only the secondary circuit.

The controller usually is self-contained, with the resistance mounted back of the panel. It is necessary to install a separate switch to handle the primary circuit.

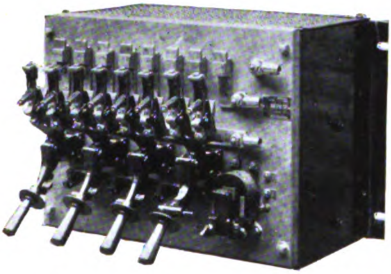
A modification of the face plate type controller which is particularly suitable for large capacities, and which is being built in sizes up to several thousand horse power, is the controller illustrated in Fig. 1. This is the multiple-lever type in which a series of switches similar to those on circuit breakers control the starting resistance. These levers are equipped with laminated-brush main contacts and carbon-to-metal auxiliaries, which are easily renewable, and which handle the arc due to the commutation of the resistance. The great advantage of this controller is that the starting resistance cannot be cut out too suddenly, because the operator has to close one handle after the other, which requires some appreciable time. The controller illustrated is equipped with a no-voltage release, which, is connected in the primary circuit, so that all of the resistance is inserted when the primary switch is opened or when the primary power supply fails. It is advisable to install a no-voltage release primary switch, so that the motor is entirely cut-off the line in case of failure of power. Upon the closure of the primary switch, all resistance is already inserted in the circuit, and the motor may be started up in the usual manner.

The starting of squirrel-cage motors with resistance in the primary circuit is to be recommended only for small machines which start without load. The squirrel-cage motor is usually designed to start with between 1½ and 3 times its normal torque, and a corresponding starting current varying from 7 to 3½ times its normal current. The higher the current, the lower is usually the starting torque. For a given motor this starting torque is proportional to the square of the inrush current or starting voltage, and therefore a comparatively slight decrease of the inrush current by means of resistance will cause a large decrease of the starting torque. Hence this method is not to be recommended where motors have to start frequently and under heavy load.

The face-plate type controller for use in connection with slip-ring motors, on the other hand, is a very satisfactory device if only infrequent starting is required. As with all face-plate type controllers, the limitation of this type lies in the fact that very heavy currents cannot easily be handled on sliding contacts, the multiple-lever type is used where the current to be handled becomes too high. The face-plate type controller may also be used for speed regulation. For larger sizes we would rely also upon the multiple lever type controller.

Fig. 2 shows how the face-plate type speed regulator may be interlocked with overloads and a primary switch so as to permit of starting and stopping from a distance.

It would seem possible to stop the slip-ring type motor by simply opening the secondary circuit, but this is not considered good practise because the closing of the primary circuit of an induction motor with the secondary circuit open may give rise to serious voltage surges which endanger the insulation of the motor windings. Controllers should therefore always be arranged so that the primary circuit is opened for stopping. The opening of the secondary circuit without opening the primary circuit has another disadvantage, namely, that the motor continues to be excited from the primary circuit and there is a great loss of energy due to the iron losses on both the stator and the rotor. The rotor iron losses are higher at standstill than



[SIMON]

Fig. 1—Multiple-Lever Type Secondary Starter with No-Voltage Release

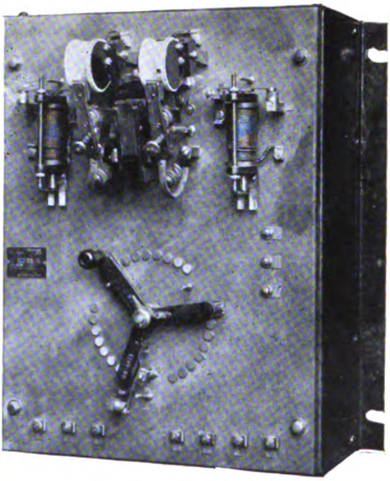


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Fig. 2—Secondary Face Plate Type Speed Regulator with Primary Switch and Overload Relays

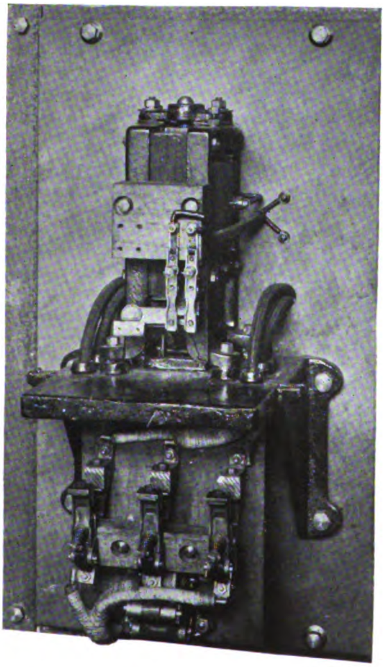

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Fig. 4—Small Solenoid-Operated Oil Switch with Tank Removed

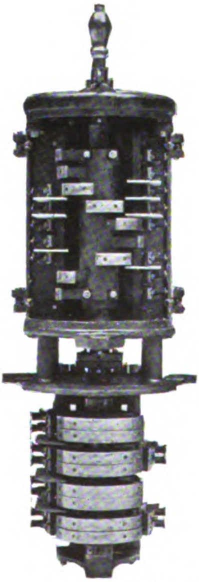

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Fig. 3—Alternating-Current Drum Controller with Primary Oil Switch

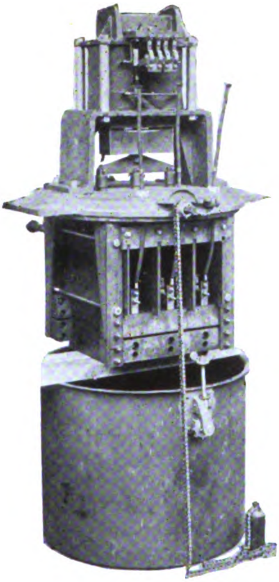

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FIG. 5—LARGE SOLENOID OPERATED OIL SWITCH WITH TANK REMOVED

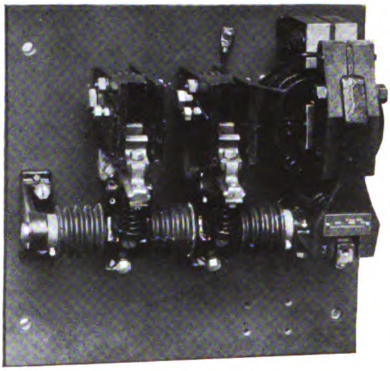

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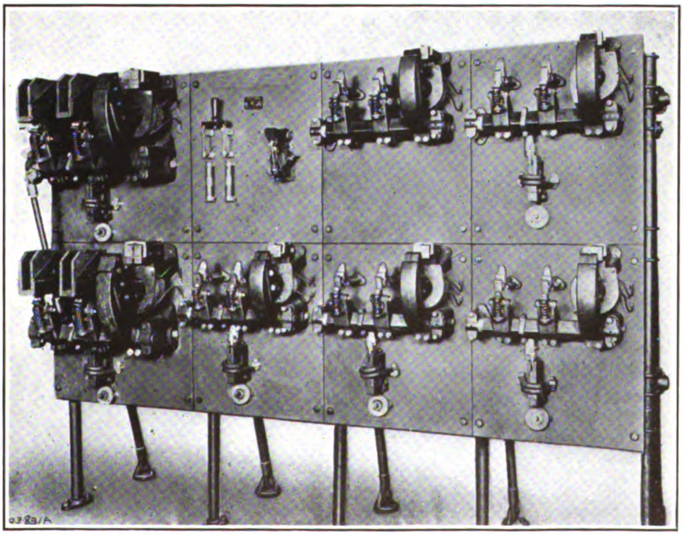
FIG. 6—DOUBLE POLE ALTERNATING-CURRENT CLAPPER SWITCH



[SIMON]

FIG. 7—PANEL WITH ALTERNATING CLAPPER SWITCHES AND SECONDARY SERIES RELAYS

they are when the motor is running at full speed, as the frequency in the rotor at standstill is equal to the primary frequency. Unless the motor is designed very liberally, the lack of ventilation may cause a burnout, though only the magnetizing current is flowing in the primary circuit.

Where infrequent starting is required, the resistance has sometimes been immersed in oil in order to give a higher starting capacity, although this method has never found a great deal of favor in this country on account of the inconvenience of the oil tank. The only advantage claimed by its advocate is the saving in spacing and cost. The saving in space, however, is only small, and under American manufacturing conditions there is no saving in cost, as the oil tank and increase in weight generally causes an increase in cost which far outweighs the saving in resistance materials. Furthermore, in large capacities, the controller can only be arranged for floor mounting, and in this case, it cannot compare with the open-type starting resistance which permits of a very light and pleasing design, and which can be arranged for mounting in any position.

A face-plate controller of special design is sometimes used for crane work where slip-ring motors have to be reversed frequently. This controller has two fronts, one of which serves as a reversing switch for the primary circuit, while the second, provided with a three-arm lever, controls the secondary circuit of the motor. The controller is equipped with renewable segment and skate-shoe type of contacts. This controller is suitable for smaller capacities of crane motors up to perhaps 50 h.p. Its only disadvantage is that the contacts are exposed and an operator might easily touch them. It has, therefore, been considered preferable in late years to enclose the contacts entirely and so this controller has been replaced more or less by the well known drum-type controller. The general design of this controller is so well known that it hardly needs any comment. The contacts controlling the secondary resistance are arranged so that the latter is cut out in rotation, one step in one phase at a time. The different phases are therefore only balanced on a limited number of points, but this is not objectionable if the stepping in the different phases is arranged so that a minimum of unbalancing is obtained at all times. It has been found that an unbalancing up to 40 per cent in the relative values of the currents in the three rotor phases does not seriously affect the operation of the motor.

Where large amounts of energy are handled in direct-current drum controllers, a blow-out is used to extinguish the arc due to the opening of the circuit. Such blow-outs are not so easily adapted to drum controllers for alternating current and therefore some other means have to be adopted for handling larger currents. The problem has been solved easily by the use of an oil switch, and it is now universal practise to interrupt the circuit of larger motors in oil. For this purpose an oil switch, containing the primary contacts, is usually mounted below that portion of the drum which handles the secondary circuit, or behind the drum. In the first case, the switch is, usually, also of drum construction, the same as the rest of the controller. In the latter case, the switch may be in the nature of an oil circuit breaker construction. The drum controller lends itself not only to the control of motors for intermittent service such as cranes, etc., but also to the speed regulation where the motor runs at a definite fixed speed for the greater length of time. The construction of these speed-regulating drum controllers is the same as those for intermittent service.

Fig. 3 shows a larger size drum controller in which the primary circuit is arranged at the bottom, and is immersed in oil. The oil tank which screws to the top plate of the bottom portion is not shown in the illustration.

When drum controllers are used for intermittent service, such as cranes, and the circuit has to be interrupted frequently, care must be taken in the design of the primary switch, especially if it is immersed in oil. The energy which is dissipated on the interruption of the circuit in the oil must be carried away, as heat, through convection and radiation. If the cooling surfaces of the oil tank are too small, the oil temperature may be raised to a dangerous point which may cause an explosion. This will blow all of the oil out of the tank, and may cause the destruction of the oil switch, or a fire. In order to avoid this, the tank must not only have sufficient oil capacity, but it must also have ample radiating surface.

While touching on the question of oil for breaking the motor circuit, we shall discuss at some length some other questions bearing on the design of oil switches in general for controller work. In the design of oil switches used for circuit breakers the designer usually endeavors to reduce the amount of oil required to a minimum on account of the fire risk. Such circuit breakers operate but very seldom, and therefore the heat storage capacity of the oil and the radiating capacity of the tank are of minor importance. This is different in case of oil switches used for controller work, for they have to operate frequently. In this case, we have to design the switch with ample heat storage and radiating capacity, and a switch which may be very satisfactory as a circuit breaker would not necessarily stand up under controller service conditions, as has been proved by the frequent failures in cases where primary oil circuit breakers have been adopted for drum control for intermittent service without any modification.

Figs. 4 and 5 show respectively a small and a large capacity switch constructed with the above mentioned points in view. It will be noted that the contacts are arranged in such a manner that the arc is formed horizontally and not vertically as in the usual circuit breaker construction. This has proved to be very valuable, as the arc is apparently extinguished quicker, and therefore the oil is not carbonized as rapidly as with a vertical break.

The switch shown in Fig. 5 has been built in capacities up to 500 amperes at 6600 volts. In an installation where the switch handles a 1000-h.p. three-phase motor, and where it has been installed for five or six years, it controlled this motor circuit some fifty thousand times, and not the slightest amount of carbon has been found in the oil surrounding the contacts, although a good deal of deposit is found at the bottom of the tank. The reason for this is, that with the movement of the contacts as arranged in this switch the oil deposits are not stirred up as violently as they are in the usual oil circuit breaker.

SOLENOID TYPE CONTROLLERS

Drum controllers are now manufactured in capacities up to several hundred horse power, but as the sizes of the motors to be controlled increase, the contact parts become larger and more numerous, and therefore the power to be exerted for operating the drums also increases tremendously. The limiting capacity for the operation of a drum controller is the power which can be exerted without strain by the operator. Another limiting feature in the use of the drum controller is the wearing of the contacts. The contacts at the different points are made and broken slowly, and this necessarily increases the amount of wear due to the arcing, where very large powers have to be handled. The arcing and the resulting wear, is consequently severe.

Where the drum controller is insufficient to handle the required capacity, or where very frequent operation is necessary, and it would tire the operator when handling a large drum, a multiple solenoid type of controller is resorted to. This consists of a number of solenoid operated, or clapper switches, as illustrated in Fig. 6.

Fig. 7 shows panels with a number of magnet switches mounted thereon. The switches shown in the illustration are suitable only for low-voltage currents, usually up to 550 volts. Where higher voltages have to be handled the solenoid-operated oil switch is by far preferable and is the most universal device. We show, however, in Fig. 8 an air-break switch arranged for 2200 volts, which switch has been used successfully in several instances.

The multiple solenoid controller consists of a number of clapper switches as illustrated. The magnets of the clapper switches are energized from a pilot controller, which, therefore, has only to handle the magnetizing current of the magnets. The pilot controller consists of a small drum or similar device.

The simplest form of the multiple solenoid controller is non-automatic in operation. The energizing of the different clappers, and the speed of cutting out of the resistance is left entirely to the skill of the operator. For large systems this mode of operation is, of course, objectionable because too rapid handling of the master controller will cause excessive current surges on the line, and undue stress on the motor and machinery. Therefore, automatic control is resorted to. This type of controller is the most important to the steel mill engineer. The automatic feature of the controller consists of one or more current-limiting relays, which are connected either to the primary or the secondary circuit of the motor, and which prevent too rapid cutting out of the resistance. The operation of this current-limiting relay is well known, and it has been used on direct-current motors for a good many years. We shall therefore discuss here only those features which distinguish it when used in alternating-current. systems.

The largest field for the current relay controllers for alternating-current motors is, of course, the slip-ring type. In this motor the primary circuit is connected direct to the line while resistance is inserted in the secondary circuit and is gradually short circuited, to accelerate the motor to its full speed. Both the primary and secondary current vary with the load and the speed under normal conditions. The secondary current is approximately proportional to the torque exerted by the motor in about the same way as in a shunt-wound direct-current motor. The secondary current becomes zero when the motor runs idle. The primary current, on the other hand, is not a straight line function of the torque because the primary circuit supplies, besides the load current, the magnetizing current of the motor. This magnetizing current in modern motors is about 30 per cent of the full-load current.

There are today two methods of operating automatic controllers with current-limiting relays; one method is by putting one or several relays in the primary circuit, and the other method by putting the relays in the secondary circuit of the motor.

Fig. 9 shows a relay arranged for connection to the primary circuit. The primary relay requires for a certain range, between maximum and minimum torque, at which the relay is to act, a more accurate adjustment than the secondary relay, because the primary current does not fall off as rapidly as the torque. It has the further disadvantage that it cannot be cut out when it has done its work, except by the addition to the controller of another switch of sufficient capacity to handle the primary circuit. The installation of such a switch is objectionable on account of its cost. The primary relay, therefore, has to be designed for continuous service which makes it rather bulky and sluggish on that account. On the other hand, the secondary relay can be connected so that it is cut out by the same switch which cuts out the secondary starting resistance, and therefore would have to be designed for very intermittent duty only, and would be correspondingly light and sensitive.

Fig. 10 shows a multiple-relay type of controller with relays in the secondary circuit, one relay being employed for each step of resistance, and the different relays are so connected that they always form the star point of the resistance in circuit, and are cut out when the corresponding resistance step is cut out of circuit by the succeeding clapper switch. As the relay itself forms the star point of the resistance, and therefore the potential difference between any two points of the relay is only equal to the drop in the relay coil, it is necessary to insulate these coils only very lightly from each other.

The relay in the secondary circuit has an apparent disadvantage due to the change in frequency of the current in the secondary circuit. When a motor operating on a 25-cycle circuit having a slip of 5 per cent reaches normal speed, the frequency in its secondary circuit is only $1\frac{1}{4}$ cycles per second. As the relay has, of necessity, very light moving parts, this low frequency would cause it to pump up and down, unless it was provided with some means for limiting such pumping, such as a shading coil, which at low frequency is really not very effective. Another way to avoid the pumping is to make use of the fact that the total pull exerted by three equal coils which are con-

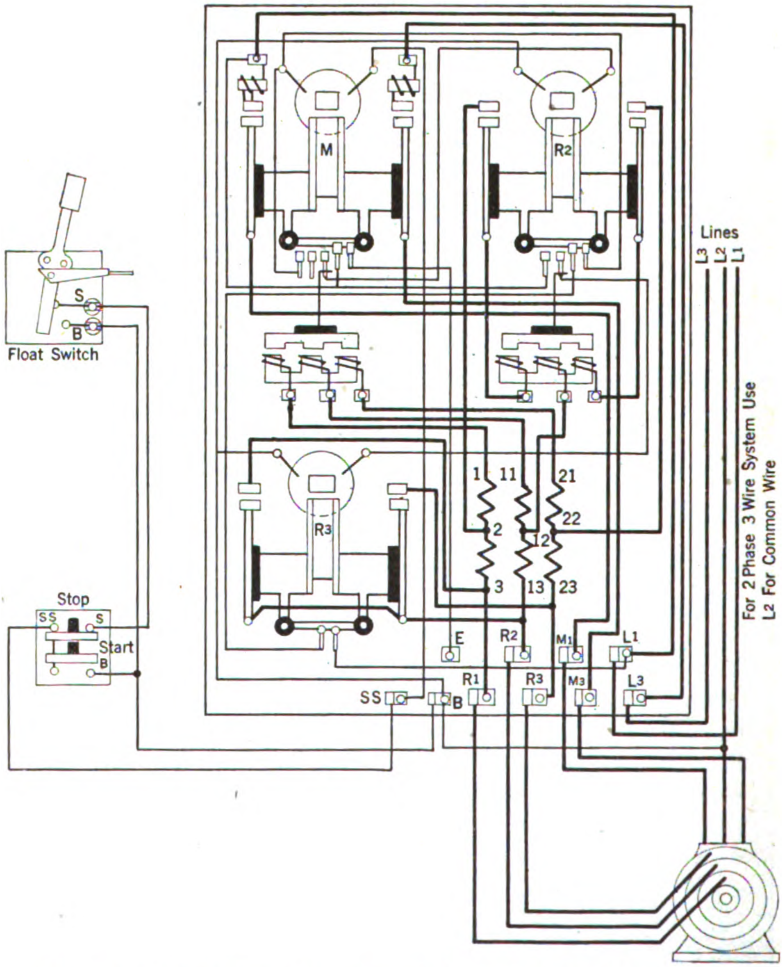


FIG. 10—CONNECTION DIAGRAM OF SERIES RELAY SELF STARTER

nected in the three phases of the secondary circuit is constant as long as the current is balanced and constant. These relays are wound with three coils which are connected together at one end, while the other ends are connected to the respective clappers and resistances. The relay has an absolutely constant pull regardless of the frequency of the secondary circuit. It can therefore be made more sensitive than a relay which is connected to one phase only, and is provided with shading coils or other means to prevent it from chattering. As mentioned above, the use of the shading coil will not really protect against chattering. In order to get a constant pull with this arrangement it will be necessary to have the shading coil flux displaced 90 deg. from the main flux, and to have both of equal magnitude. This result cannot be accomplished, and therefore the relay will have a tendency to chatter as the frequency in the secondary circuit decreases with increasing motor speed. The pull on the plunger of the relay varies therefore between a given minimum and maximum, even with constant effective current flow in the secondary circuit, and when the frequency is low, and the inertia of the plunger which tends to hold it up is relatively small, the relay will drop before the effective current in the secondary circuit is equal to that for which the device is adjusted. Hence such a relay will always work more or less erratically, and at the best it will require a much wider limit of setting than the three-phase relay described above.

It is, of course, not necessary to have the three coils of the secondary relay connected so as to form the neutral point of the resistance. In some cases it is necessary to have the three coils insulated from each other. This is the case where the relay is used as a "jamming" relay, in which case it has to be connected ahead of all of the resistance and directly behind the slip-rings of the motor. Where the secondary circuit has a relatively high voltage, and in motors of large capacity, it is, of course, possible to connect the relays to current transformers inserted in the secondary circuit instead of connecting them directly into the latter. This is particularly valuable in case of the "jamming" relay, which otherwise would always have to be insulated for the maximum secondary voltage.

There is still a good deal of discussion as to the advisability of using a single relay controlling several steps of resistance instead of a separate relay for each step. It seems to the writer that the latter method is to be preferred, because it is possible to set the different relays for different currents. This is a particularly valuable feature in machinery such as centrifugal pumps and so on, where the torque required to accelerate the motor varies between the low speed and high speed. Each relay is then set for the different accelerating currents, a feature which cannot be obtained with a single relay in the primary or secondary circuit.

The simplest kind of current relay controller is a non-reversible self-starter for use in connection with machinery which always revolves in the same direction. Instances of this kind are centrifugal pumps, blowers, compressors, and so on. The operation of such machinery represents nothing that is novel in the art, and it therefore need hardly be discussed here. The controller consists of a suitable clapper for the primary motor circuit operated by a low-voltage magnet coil, and it has a number of switches controlling the resistance in the secondary motor circuit. The secondary circuit of the motor is usually designed for comparatively low voltage, and therefore the usual clapper type construction, as illustrated, may be employed.

The secondary switches are controlled by three-phase series relays connected and constructed as described above.

Where the supply circuit has a voltage above 550, it is necessary to employ a step-down transformer which supplies current for the pilot circuit operating the magnets. In a previous paragraph we have already touched upon the considerations which bear on the construction of such high-tension switches.

A type of controller which finds more frequent application in steel mill practise than the non-reverse automatic starter is the reversible automatic controller. Its usual application is for intermittent service requiring very frequent starting and, quite often, speed regulation at all controller points. The service performed is very much more severe than that of non-reversible controllers. Instead of putting in one switch for the primary circuit, two switches suitably interlocked are used, one for each direction of rotation of the motor. The secondary circuit of the motor is controlled in the same manner as on the non-reversible controller. The resistance has to be designed with a considerably heavier capacity, and in some cases requires even continuous carrying capacity on all points. Such controllers are used in connection with mill tables, cranes, hoists and other machines.

The various applications of this controller in steel mills and

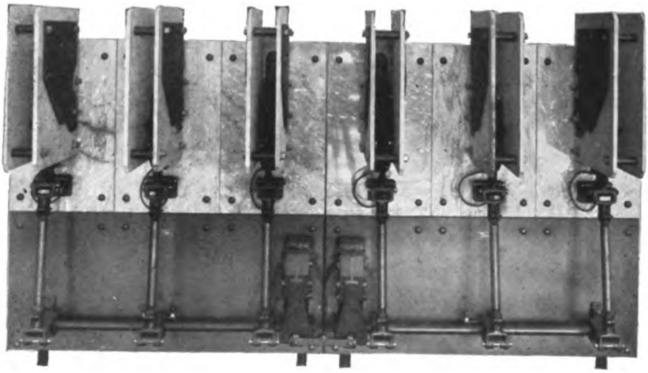


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FIG. 8—2200-VOLT TRIPLE-POLE AIR-BREAK REVERSE SWITCH

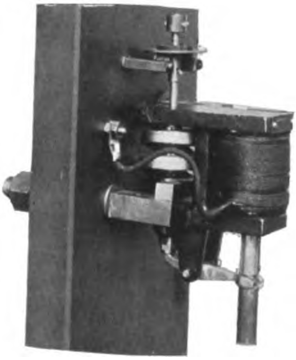

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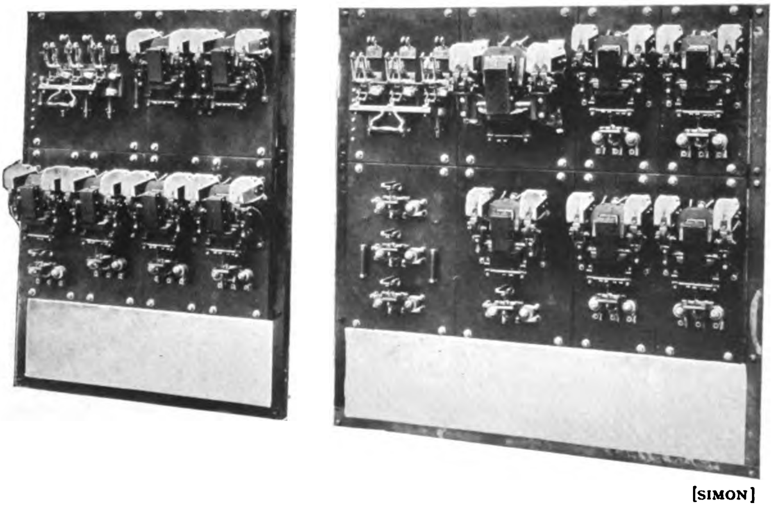
FIG. 9—PRIMARY SERIES RELAY



[SIMON]

FIG. 11—CONTROL PANELS FOR ELECTRICALLY-OPERATED SHOVEL

allied industries requires many special features, and we shall further discuss some of the typical applications of these controllers.

Electrically-operated shovels and drag lines have not been discussed very much in electrical literature, though they present some very interesting problems, and since the writer has some interesting data on hand, we shall discuss these. The first shovel installations used direct-current motors, and it was considered not only desirable but absolutely necessary to build the controller and the motor so that the electric shovel would exactly duplicate the operating cycle which was found the most suitable for the older steam machines. The first installations were not quite as successful as had been expected, and designers have gradually come to the conclusion that it is best to somewhat modify the operating cycle of the shovel, or, at least, the mechanical design of the shovel in order to fit the electric motor. On account of the necessity of transmitting the power to the shovels, usually over long distances, most of the shovels which were installed in late years are equipped with alternating-current motors, and these are the ones which we shall treat here.

Shovels of capacities ranging from 60 to 100 tons are equipped with three motors, one for hoisting, one for the swinging and one for the thrust motion. Except on the smaller machines, all motors are controlled by full automatic controllers. On the smaller machines, the thrust motion has a drum controller.

Fig. 11 shows the controller panels for a 100-ton shovel. The main hoist motor is equipped with a non-reversible, automatic self-starter, which in turn is controlled by a multiple speed master drum. This controller is provided with a number of "jamming" relays, which reinsert resistance in the rotor circuit of the motor when a certain maximum torque is reached, so that if the motor is stalled by encountering an excessively heavy obstruction in the stone bank, the torque is automatically increased up to the maximum torque which the machine can stand. This avoids the stalling of the motor with the resistance short-circuited, which would result in the opening of the circuit breaker and the loss of power. The hoist motor is non-reversible, because there is always a sufficient load on the motor to overhaul it and to lower the bucket of the machine when the brakes are lifted and the power supply to the motor is cut off.

The swinging motion is controlled by a full reverse automatic self-starting controller, also provided with a master drum controller which permits of running at any speed. The use of current-limit relays has proved particularly advantageous in this instance, because the inertia of the boom of the shovel is quite high, and therefore it would be quite possible for the operator to accelerate too fast and to lift the shovel off the track, if no current-limit relays were provided for.

This is still more important in case of the drag line, the boom of which has a still greater inertia on account of its extreme length. In other respects the drag line operation is the same as that of the shovel, except that it has no thrust motion, the bucket being operated only by the manipulation of the hoisting machine.

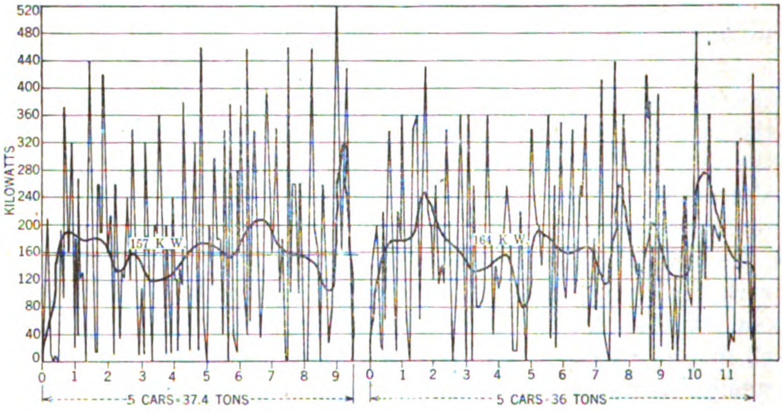


FIG. 12—CURRENT CONSUMPTION OF AUTOMATIC SHOVEL

The thrust motion of the shovel is also controlled by a reverse controller with a few steps. In this case it is designed so that the motor speed is about inversely proportional to the torque, and therefore the motor is run with sufficient permanent resistance in the secondary circuit so that its speed-torque curve with the controller in the maximum speed position is nearly a straight line, and the motor exerts the maximum torque when stalled. In this way it is possible always to have the bucket follow the uneven curvature of the bottom of the pit, when the hoisting machine is operated, without the danger of wrecking the machinery by exerting undue stresses on the thrust or hoist motion.

The diagram of Fig. 12 relates to the power consumption of an electric shovel equipped with automatic controllers. A second shovel of the same bucket and motor capacity and of the same weight, is of German make, and we therefore shall call it the "German" shovel, whereas the first shovel with automatic controllers is of American make, and we call it the "American" shovel. The tests were made on high grade iron ore in the Swedish iron mines in Lapland, and the following results were obtained.

COMPARISON OF ELECTRIC SHOVELS IN SWEDEN

	German		American	
Maximum peak	390 kw.	380 kw.	520 kw.	480 kw.
Next four peaks	370 kw.	340 kw.	460 kw.	420 kw.
Amount of excavation	36.5 tons	36.5 tons	37.4 tons	36 tons
Average load	105.4 kw.	105.4 kw.	157 kw.	164 kw.
Time to load 5 cars	20 min.	22 min.	9½ min.	11¾ min.
Kw-hr	35.1 min.	38.6 min.	24.8 min.	30.8 min.
Kw-hr. per ton	0.96	1.06	0.662	0.855

It will be noticed from the above table, that, while the maximum current peaks of the automatic shovel are higher, the shovel handled nearly twice the amount of material in a given time as was handled by the non-automatic shovel, and the power consumption per cubic yard of material handled is considerably less on the automatic shovel. If the cost of power, depreciation, interest, labor and other items, were added, it would be found that the operation of the automatic shovel is considerably cheaper than the operation of the non-automatic shovel, and that in this instance, and in a good many others, the increased cost of the more expensive installation more than pays for itself within the first year.

An important machine for steel mills, and mine service is the electrically driven pump. When installed in the mine the pump controller has to be designed along the same lines as the controller for mine fans, and special provision has to be made for automatic re-starting after failure and subsequent restoration of the current supply. In some instances it is possible to have the pump started by hand operation under no-load conditions. In this case, the operator will close the inlet and outlet valves of the pump before it is started. We have reference here primarily to centrifugal pumps, which are used more and more universally today. Under the conditions outlined above, the pump requires only a very low starting torque and therefore it is very often possible to employ a squirrel-cage motor with compensator type starter. Under some special conditions the pump may even be started with a very low torque without manipulation of the inlet and outlet valves, and it may, at the same time, be desirable to use an automatic controller, thereby doing away with the necessity of a constant attendant. In recent years automatic compensator type starters have been adopted and have proved to be quite successful. It has been found that such starters may be operated either with current- or time-limit relays. In controlling the acceleration, the current-limit relay has the advantage of keeping the current peaks always within predetermined limits irrespective of the time it takes the motor to accelerate, and irrespective of any possible variations in the starting torque. On the other hand, if for any reason the starting torque required should increase appreciably, the current relay might not permit the controller to apply full voltage to the motor terminals and, therefore, the motor would always run on the low-voltage tap of the starter, and both the motor and the starter might ultimately burn out. This danger is enhanced by the fact that the current of the motor changes only slightly during the first part of the accelerating period and therefore the current relay has to act on very small changes of current; in other words, has to be very sensitive. This extreme sensitiveness cannot always be maintained under ordinary operating conditions, and with only disinterested supervision it seems more desirable to use the time-limit relay acceleration for such controllers, despite some inherent disadvantages which such controllers undoubtedly have. If the starting torque required of the motor is liable to vary, the current which it takes with the time-limit relay also varies. This is the main objection to the time-limit relay acceleration; but, on the other hand, as long as the relay operates at all, it is not possible for the motor to run indefinitely on the starting tap of the starting transformers, but after a certain time, which normally should be sufficient to bring the motor up to proper speed, it will be brought to the full speed point, and the transformers are cut out, thereby eliminating the danger of burn-out due to low voltage.

On the other hand, if the motor should not start at the first controller tap, it would start when it is thrown on a higher tap or on the full voltage. This may not be always the best thing for the mechanical parts of the machinery, but with proper mechanical design, it would in no event be so disasterous as the stalling of the motor and of subsequent burning out, due to the inability to start at low voltage, as in the case of current-limit acceleration.

While we are dealing with the handling of raw materials and the operations in the mines, we wish to call attention to a very interesting problem involving semi-automatic or automatic controllers for an entire series of motors; this is the motor drive of a line or several lines of belt conveyors. In cases where a great many belts are driven by individual motors, it is desirable to prevent an accumulation of material on any one of these belts, due to the shut-down of its corresponding motor. It is therefore necessary to interlock the controllers for the various belts in such a manner that in case of stoppage of any motor all preceding belts also come to a standstill, stopping the delivery of material to the belt in trouble, so that the motors can only be started in the reverse rotation in which the material is handled by the various belts. A number of such installations have recently been completed for coal and ore belts. In one notable installation, covering some thirty belts, the interlocking spoken of has been accomplished by means of centrifugal governors, which are driven by the countershafts on the belts, and which when standing still open any interlocking circuit which is in circuit with the preceding motor. In another instance, all belts, crushers, etc. belonging to the system are controlled by compensator type starters, the no-voltage releases of which are interlocked so as to get the results desired as outlined above. This shows to what extent automatic controllers can be adapted to the steel mill industry to supersede inefficient labor.

The electric drive of the coal and ore bridge has received a great deal of attention of late years. This problem is important because most of the raw material is transported by water on the Great Lakes, and since the shipping season is comparatively short, it is desirable to load and discharge vessels as quickly as possible to get the highest rate of return from them. The loading and unloading equipments therefore have been designed to enable much more rapid handling of material than is found anywhere else in the world. I hardly need to mention here the feats that are being accomplished almost daily in the unloading of ore and coal vessels, and there is being presented today another paper dealing particularly with coal and ore handling machinery.

One of the most important installations in the blast furnace plant is the skip hoist, on the operation of which depends the smooth running of the furnace. Skip hoists are also used in mines, cement plants, and so on. The writer is not familiar with any alternating-current installation on blast furnace skip hoists, but there have been made some notable installations of skip hoists particularly in cement plants.

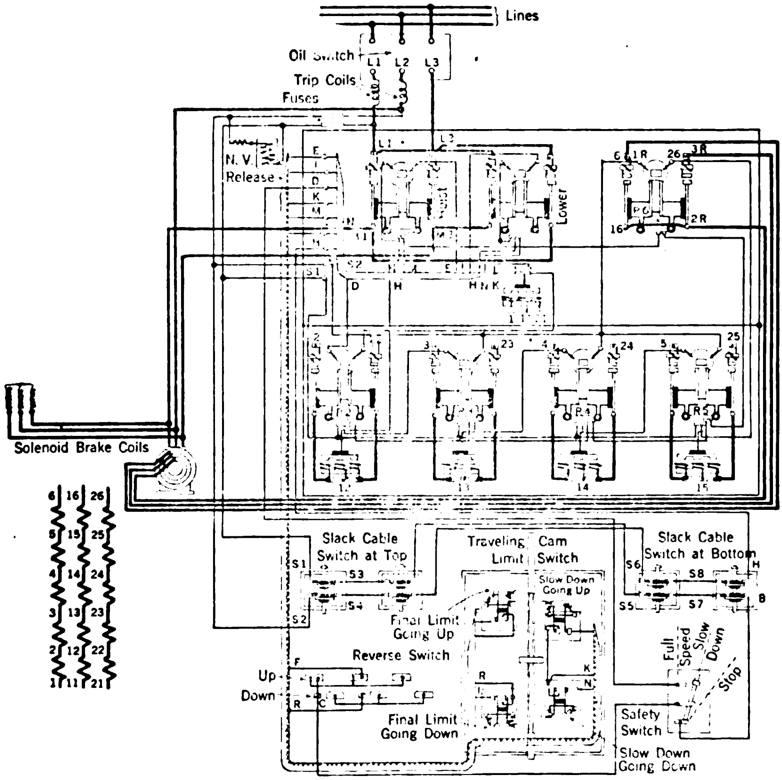


FIG. 13—CONNECTION DIAGRAM FOR ALTERNATING-CURRENT SKIP HOIST

Fig. 13 shows a diagram of a balanced automatic skip hoist in a cement plant. These hoists are designed for a maximum pull on each rope of approximately 11,000 kg. (25,000 lb.)

These rope pulls are balanced by the weight of the descending skip on the other side, so that at the time of starting, the unbalanced rope pull which the motor has to handle is approximately 7000 kg. (17,750 lb.) Each hoist is designed to handle 7200 kg. (16,000 lb.) of stone per trip. The skip weighs 5400 kg. and the incline is 67½ per cent from the horizontal. The hoists are equipped with a 125-h.p., 550-volt, 60-cycle, three-phase motor, continuous duty, and the gear is designed to give a maximum rope speed of 200 ft. per min. The actual hoisting distance is 139 ft., and each hoist is designed for a capacity of 400 tons per hour. The operation of the hoist is entirely automatic, the starting being initiated by the loaded car, and a solenoid brake is mounted on the motor shaft to bring the hoist to rest. The hoist stops always within three inches of the same point. By slightly overloading the skip each hoist has handled 4700 tons of stone in ten hours.

Another very important application is the electric drive to mine hoists. Where very large powers have be to handled special arrangements are usually made, such as the installation of an Ilgner system, which is always to be recommended, except where the power supply is practically unlimited, and can therefore take care of the rapidly fluctuating load of the hoist. For smaller powers the slip-ring type motor is quite suitable, with a series-relay type reversible hoist controller. The satisfactory operation of the series relays may best be judged by the fact that in a certain installation the current peak at starting never exceeds 80 amperes, the maximum current which is allowed by the power company. Some figures relating to this hoist may be of interest. The hoist was guaranteed to require not in excess of 90 amperes when handling 3200 kg. (7000lb.) when operating balanced or unbalanced; the maximum rope pull at the drum would not exceed 3700 kg. (8200 lb.) in the latter case. The current input specified is measured on the primary side of the transformer, with a primary voltage of 2080 volts, at 60 cycles. The calculations showed that, on the guaranteed condition of load, the maximum current peak should not exceed 80 amperes which checks up exactly with the graphic curve. The motor is 200 h.p., 440 volts, 60 cycles. The controller, in addition to the switches handling the motor circuits, is equipped with a high-tension type magnet switch which cuts off the current of the transformer whenever the motor stands still, so as to avoid the primary losses of the transformer.

The most important motor application in the steel mill is the main drive for the rolling mill. A great deal of discussion has taken place during the last ten years regarding the most advisable arrangement for this installation. European practise today uses the two-high mill driven by reversing direct-current motors, which are supplied from a motor-generator set with flywheels, and which are controlled according to the variable voltage system. On the other hand, in this country, operating men have preferred a three-high mill driven by a constant speed motor running always in the same direction. This enables the use of high-voltage alternating-current motors directly supplied from the power station and eliminates the motor-generator, thereby eliminating several links from the transmission system and increasing its insurance against break-down. It is usually pointed out that such an installation is more reliable and cheaper in operation on account of its higher efficiency, but it is the writer's belief that there is no universal solution for all cases, and there can be no doubt that where conditions are suitable, the Ilgner system is equal if not superior to the American system of constant speed motors with the three-high mill.

We do not propose to discuss at length any of these installations, but we give operating data of such an installation, consisting of two 500,- one 750- and one 1000-h.p. motors. The motors are 2200-volt, three-phase, 25-cycle machines. The controllers are arranged for forward and reverse rotation and also for automatic braking. The reverse is required only for emergency; for instance, when the mill becomes clogged. In this case, the primary circuit of the motor is reversed and it is possible to accelerate the motor up to full speed in the reverse direction, if this should be desired.

Automatic braking is obtained by energizing two of the three phases of the stator with direct current from a low-voltage source of supply, and then gradually cutting out the resistance in the rotor circuit of the motor. The motor then operates as a synchronous generator with variable frequency.

A number of steps of permanent resistance are employed, which may be cut in and out by knife switches. The purpose of this resistance is to adjust the average slip of the motor, so as to enable the flywheel, which is put on the motor shaft, to smooth out the current peaks during the cycles of operation. Depending upon the material to be rolled, the average load on the motor is higher or lower, and therefore it becomes necessary to adjust the slip resistance to the average load.

The controller is operated through a master drum having two handles, one for acceleration, and the other for setting the direction of rotation. This second handle will also complete the dynamic braking connection in its center position. The two handles are interlocked in such a manner that the accelerating drum must always be returned to the position in which all accelerating switches are opened and all resistance inserted in the rotor circuit before the direction switch can be operated. The acceleration and the dynamic braking may be entirely automatic. It is only necessary for the operator to bring the accelerating drum handle to the full speed position, and the motor is then accelerated or slowed down by the automatic action of the current-limit, relay in the secondary circuit. This tends to keep the torque, during acceleration and braking constant. The high-voltage switches employed in the primary circuit of this installation have been described before. It should also be pointed out that the controller is equipped with overload relays connected in such manner that the drum has to be returned to the off position to enable restarting after the overload relays have operated.

Some data relating to the motors are as follows: One 500-h.p. motor, 365 rev. per min., flywheel 10-ft. diameter, 10,000-lb. rim; one 500-h.p. motor, 12-ft. 8-in. diameter flywheel, 30,000-lb. rim; one 750-h.p. motor, 244 rev. per min., 12-ft. 8-in. flywheel, 30,000-lb. rim; one 1000-h.p. motor 180 rev. per min., 17-ft. flywheel, 60,000-lb. rim.

The 1000-h.p. motor requires about five minutes for its acceleration with an initial inrush of 750 kw., and subsequent peaks of approximately 600 kw. The current peaks of the other motors are proportionate. According to the report of the engineer in charge, the controllers for these motors, after the installation was completed and adjusted, never required any attention, except usual inspection, during the five or six years of installation. This would indicate that alternating-current controllers can be built today sufficiently reliable for the most severe service conditions.

We have outlined in this paper some of the typical installations of alternating current controllers, and we have touched upon some of the typical points in the design of such controllers, and the author will be glad if the paper funishes the basis of a general discussion on the subject.

Presented at the 3d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1915.

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ELECTRICAL PORCELAIN

I. TESTING WITH A HIGH-FREQUENCY OSCILLATOR. II. THE PROBLEMATICAL POINTS OF MANUFACTURE. III. EXPERIENCES AND EXPERIMENTAL INVESTIGATIONS

BY E. E. F. CREIGHTON

ABSTRACT OF PAPER

Part I treats of the reasons for using the high frequency oscillator for testing porcelain insulators. The oscillator is a combination of a 60-cycle transformer, a condenser, a spark gap, and an oscillation or coreless transformer. The 60-cycle potential charges the condenser and the condenser discharges through the gap and the coreless transformer. This sets up high frequency wave trains of the same nature as the wave trains that take place on the transmission line. This high frequency potential strain is the only kind that damages the insulators. The 60-cycle potential is always far below the puncture potential and arc-over potential of the insulators.

In Part II it is shown that the principal factors in the manufacture of porcelain which affect the final product are:

1. The choice of ingredients,—ball clay, china clay, feldspar, and flint.
2. Is the problem involved in getting a homogeneous mixture of these pulverized materials.
3. Is the problem of drying out the moisture without causing unequal contractions which crack the green porcelain.
4. Is the early dehydration in the furnace in which as much as 14 per cent of moisture is given out.
5. Proper time and temperature for vitrification.

The mechanical processes through which porcelain is carried are of the greatest importance in getting good electrical porcelain. It can be stated that defective porcelains are in general due to the accidents of manufacture, the dielectric strength of all the porcelains being passably good except for flaws.

Part III includes data on tests carried out mostly with the high-frequency outfit. An electrical method is shown of producing failure along invisible cleavage surfaces in the porcelain body. This examination should be useful to the porcelain manufacturer to indicate how nearly the porcelain is approaching to a weakness which will cause the rejection of the porcelain piece. Another method, using potential gradient to investigate the homogeneity of the porcelain, may be found of use in determining the efficiency of the pug mill which is used to mix the ingredients when the porcelain is in the early plastic stage.

1. OBJECT OF THE PAPER

IN PREPARING this paper there has been in view a number of objects. The many electrical and ceramic problems encountered are complex and widely ramified. There

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are a number of these problems which have only been mentioned. There are ceramic problems on which definite information has not yet been found. There are methods of examination of porcelain which are still in the stages of development. The experiments given are definite so far as they go but more experience is necessary to crystallize the methods into permanent forms. There is one main object which it is hoped to accomplish: namely, to call attention to the use of the high-frequency oscillator as a rational method of testing insulators.

Some of the subjects treated are listed below:

(a) A brief analysis of the general problem of continuity of service on transmission lines in which porcelain insulators assume a primary and important position.

(b) An analysis of the electrical strains which are actually imposed on insulators in practice.

(c) A description of the high frequency oscillator which has been designed to reproduce the electrical strains imposed on the insulators.

(d) A brief review of ceramic problems as involved in the manufacture of porcelain for electrical purposes.

(e) Experiences and experiments in the practical use of the oscillator and the general methods of study of porcelain.

(f) Puncturing under oil: Thickness, range of puncture voltage, form of test piece.

(g) Equivalent gap tests.

(h) Voltage of first appearance of corona on insulators.

(i) Percentage of failure as a criterion of rejection.

(j) Comparison of puncture voltage of several porcelains.

(k) Technique of examination of cracks, laminations, punctures, etc.

(l) Hot and cold tests.

(m) Tests with continuous high frequency.

(n) Study of the effect of corrugating a smooth surface and the laws of creepage spark as affected by thickness of porcelain.

(o) Methods of using super-spark potential from the oscillator.

(p) Methods of examination of quality of porcelain using voltage gradient.

(q) Determination of the proper time of test and something on the question, " Does the voltage test damage the porcelain?"

Much valuable work on electrical porcelain, comprised in a number of papers, has been presented to the American Institute of Electrical Engineers during the past few years. The recent steps taken by the committee on standardization of tests of insulators have had great value in crystallizing the known data and information into a definite useful form. It is here proposed to add further to the collected data and present a new method of testing insulators which the author believes should supplant the old standard method in which potential at a frequency of 60 cycles per second is employed.

It seems unnecessary to dwell at any great length on the engineering necessity of finding a satisfactory solution of the problem of maintaining the integrity of the insulation of electrical transmission lines. It is desirable to attack this problem from every available scientific and practical standpoint. The problems relating to the integrity of the insulator are only a part of the broad problem of continuity of service on transmission circuits. A brief review of the salient factors of the broad problems is given in the following analysis, in which the position of the problem of the insulator itself is made evident.

PART I

2. ANALYSIS OF THE BROADER PROBLEM OF CONTINUITY OF SERVICE

In the first consideration we can hope only to pursue the line of investigation relating to detection of weak and damaged porcelain insulators, and either reject them if they have not yet been installed or remove them from the line if they are already in use.

In the second consideration we may hope with confidence to overcome the causes which deteriorate the insulators after they have been put into use,—such damage as comes from unequal expansion of metal parts, cements,and porcelains. This investigation should also cover these faults which are present in the manufacture, in one form or another, such as open pores, closed pores, cracks, from unequal contractions, local strains, laminations, air pockets, localized mineral impurities, and accidental impurities in the form of threads and hair.

In the third consideration is the form of the insulator. The ideal design should be such that the porcelain shall never puncture.

In the fourth consideration is the way and means of preventing lightning from producing a potential sufficient to arc over an insulator. This involves the subject of overhead and under-hung grounded conductors; also the necessary factor of safety of the line insulator.

In the fifth consideration, assuming that in spite of all precautions an accidental arc is established around in insulator, what means may be employed to suppress such an accidental arc without causing or allowing an interruption of service? Herein comes the use of arcing ground suppressors and short-circuit suppressors.

In the sixth consideration is the condition of malicious or accidental interference with the power wires in which a heavy conducting strip is thrown across two conductors or two line wires are pushed together. The only possibility of continuing the service then lies in the use of a duplicate undamaged circuit and automatic relays to cause the nearest circuit breakers on both sides of the short-circuit to open and thus remove the faulty circuit.

In the seventh and last consideration is the rare occurrence of cyclones, floods, and sleet storms which destroy considerable length of the circuit. The only insurance against interruption of the user's service is then a local steam auxiliary or storage battery.

In this paper we are concerned with the first three considerations and a part of the fourth consideration, all of which deal directly with the porcelain insulator.

3. How Should Insulators be Tested?

We have in the past tested insulators with high potential at the available frequency of 60 cycles. In suggesting testing with high frequency it becomes necessary to differentiate between the different kinds of high frequency that can be produced by different types of apparatus. There is the continuous high frequency as given by an Alexanderson generator and there is the high frequency wave trains produced by a discharge of a condenser through a transformer having no iron core. In each case there is the question of what value of high frequency to use and what potential. These factors will be considered more in detail later but we can find immediate answer to the question of the proper tests to make by statements of the conditions to which the insulator is subjected. Insulators in practise may become faulty due to unequal expansion of metal, cement, and porcelain but even then they seldom get an opportunity to fail at 60 cycles because of the fact that every circuit has super-imposed on the 60 cycle potential occasional higher frequencies coming from switching and variations in load which reach the gradually developing faults in the insulator before the deterioration is sufficient to be affected by the 60-cycle wave. This whole question of what conditions of potential and frequency to impose in test on an insulator can be answered in the general statement; *test the insulator under the same conditions which cause its failure in actual operation.* These conditions will now be reviewed.

4. Classification of Faults in Insulators

There are two entirely distinct conditions of failure between which we must differentiate. First, complete failure of the porcelain by cracks, leaving only air and moisture as insulation between the metal terminals of the insulators. There is no need to discuss refinements of tests in this case. The desired tests consist simply in furnishing sufficient voltage to break down the air gap in the crack of the porcelain. If there is moisture in the air-gap an ordinary resistance test with a megger will show the presence of the crack. In the absence of moisture a higher voltage must be used. This calls for some portable testing outfit which can be carried along the transmission line and the oscillator is generally the best to use. Second, flaws consisting of small cracks, laminations, air pockets, porosity, etc. in insulators which withstand the normal 60-cycle potential applied to them and even the higher value of 60-cycle test potential, but will fail under the imposition of high frequency wave trains such as occur in lightning strokes, switching, etc.

NOTES ON TESTING OF INSULATORS WITH THE OSCILLATOR

5. Problem of Testing the Thousands of Insulators Already Installed

One of the most important points regarding the use of the oscillator lies in the fact that it can be made so light and inexpensive and easy to handle that it can be used by the transmission engineers and their assistants to test out insulators after they have arrived at their destination, and also to test out the thousands of insulators which have been installed during the past dozen years, and thereby to pick out the faulty ones.

6. THE CONDITIONS TO WHICH INSULATORS ARE SUBJECTED IN USE

In order to determine the nature of the desired electrical tests the following analysis is made. Insulators are damaged electrically, first, by lightning; second, by surges from switching; and third, by surges from accidental arcing grounds, and the like. The duration, voltage, and frequency of these surges will now be analyzed.

7. DURATION CHARACTERISTICS OF THE THREE KINDS OF SURGES

Lightning has the characteristic of momentary duration but a stroke may be repeated a number of times in such rapid succession that the successive strokes appear to the eye to be one stroke. There are many records taken by moving photographic films which show conclusively that lightning does come in multiple strokes.

Switching surges are also of comparatively short duration, taking place only at the moment of closing or opening of the oil switch or the blowing of a fuse.

Surges set up by accidental grounds are frequently of considerable duration, lasting many seconds or even many minutes. Single-phase short circuits sometimes cause high voltage in other parallel circuits.

8. RISE OF VOLTAGE OF THE THREE KINDS OF SURGES, AND THE FREQUENCIES INVOLVED

In each case the rise of potential also must be considered as a factor of menace to the integrity of the porcelain insulators. In the case of lightning there is no limit to the potential except that which will cause a discharge from line to ground. In the case of switching, the voltage on the line nearly always reaches double value; and with changes of ratio of capacity and inductance in the transmission circuit or with partial resonance, the surges may rise to considerably more than double line potential. In the case of arcing grounds the voltage will usually rise to double value and there are many chances of a resonant condition existing which will carry it much above double value.

9. THE OSCILLATOR TESTING SET

The testing set, as developed, is shown in Fig. 1. It consists of the following elements as shown in the diagram, Fig. 2.

a. A 60-cycle step-up transformer.

b. A condenser placed across the terminals of the high voltage coils of the transformer.

c. An adjustable gap.

d. An oscillation transformer, oil immersed, without iron core, consisting of a few turns on the primary and many turns on the secondary. The regulation of this transformer is made as good as can be obtained and, unlike the wireless outfits, there is no dependence placed on obtaining resonance for the ordinary tests.

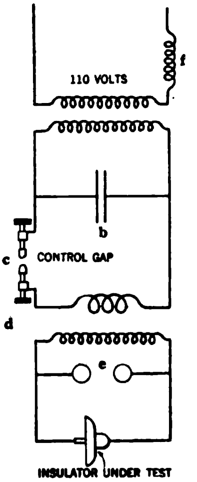


FIG. 2

Diagram of connections of the oscillator testing set for porcelain insulators.

b, condenser
c, control gap
d, oscillation transformer
e, sphere gap
f, series inductance

e. A sphere gap made up of spheres of diameter equal to maximum air gap.

f. A suitable reactor to protect the step-up transformer against the damaging effect of short-circuit when a spark takes place on the small gap.

The ratio chosen for the 60-cycle transformer is 110 volts to 13,000 volts, as both are standard and 13,000 volts is high enough to give good effects in the oscillator, in the set large enough to test ordinary single-unit insulators. This outfit is capable of producing a voltage represented by a setting of 125,000 volts on the sphere gap and is capable of operating at this value all day long continuously. This is the testing set recommended for general use. For testing single lower voltage insulators a smaller set can be built to meet the special needs.

The main frequency of the natural oscillation of such an outfit without the secondary of the coreless transformer in place is about 200,000 cycles per second. The range of high frequency recommended for testing is 150,000 to 400,000 cycles per second.

The maximum rate of discharge should not be less than 1000 kv-a. This maximum rate of discharge is not dependent on the kilowatt rating of the 60-cycle transformer but depends mostly on the electrostatic condenser.

The foregoing data cover the characteristics of a testing set which is capable of testing most of the insulators in use. It is easily manufactured and satisfactory in operation. A convenient form is shown in the accompanying illustration, Fig. 1.

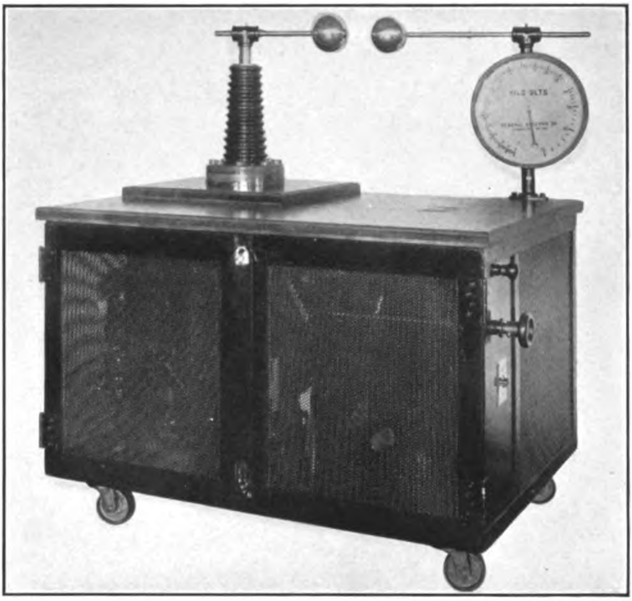
10. CONTROL OF VOLTAGE OF THE OSCILLATOR

The voltage is controlled by gradually opening the control gap shown in Fig. 2. One electrode of this control gap is connected to a long insulating rod which permits of handling while the arc across the gap is playing. In this way the voltage is gradually increased to the desired value while it is being applied to the insulator.

The control of the voltage by the use of the control gap alone gives a very simple condition and its use is recommended in spite of an increase in the number of wave trains per second at less than quarter its maximum voltage. If this increase in the number of wave trains were a serious matter it could be taken care of in either one of two ways. First, by decreasing the total time of applications of voltage to the insulator, so as to give the same total number of wave trains, when the control gap is small and sparking over more than one per half-cycle. A test of one minute with 120 alternations per second gives a total of 7200 wave trains per minute. The other method of getting a definite number of wave trains applied to the insulator could be accomplished by reducing the voltage at the terminals of the 60-cycle transformer, thus making the peak voltage correspond with the spark voltage setting of the control gap. In this way a single wave train per half-cycle will be produced.

As a matter of experience it is found that except in special cases the variation in the number of wave trains is not a serious matter in the practical testing of insulators. There are several factors involved. First, the time of test of an insulator set at one minute or ten seconds is a quite arbitrary value and the period might well be chosen as two minutes if so desired. Two minutes would correspond to twice the number of wave trains per second. It is desirable to maintain the standard of one minute for test for reasons of economy. Second, the greater number of wave trains are produced at the lower values of voltage and the lower values of voltage correspond to small insulators on which there is a large factor of safety. As the matter stands then, there are a greater number of wave trains applied to the lower voltage insulators but they are capable of withstanding it and the extra number of wave trains applied for one minute is not sufficient to cause deterioration of good porcelain.

In Figs. 3, 4, and 5 are given three oscillograms taken in the 60-cycle circuit of the oscillator which show typical conditions for three different values of voltage generated in the secondary.



[CREIGHTON]

FIG. 1

125-kv. oscillator with sphere gap voltmeter. Single terminal of the coreless transformer shown at the left to which one sphere is attached. The other terminal of the coreless transformer is grounded. The other sphere which carries the voltmeter is grounded so that it can be handled while the spark is playing.

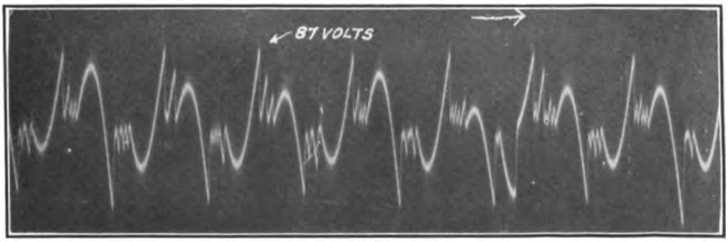


FIG. 3

[CREIGHTON]

Oscillogram of voltage in the 60-cycle circuit of the oscillator when the control gap is set for 6000 volts effective. There is only one main discharge at the control gap per half-cycle. When a spark at the control gap takes place it is indicated on the oscillogram by a sudden drop in voltage.

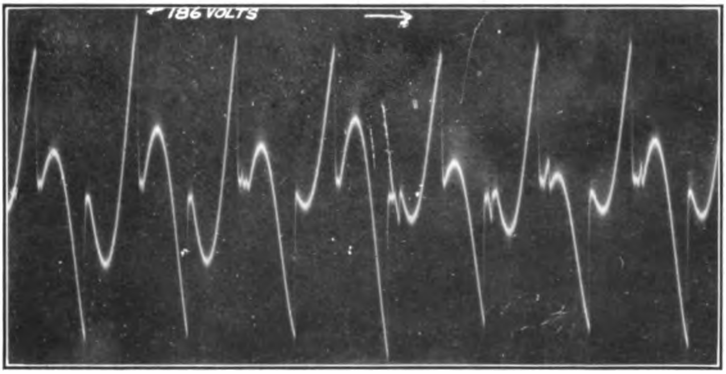


FIG. 4 [CREIGHTON]

Oscillogram of the voltage on the low side of the 60-cycle transformer when the control gap is set for 12,000 volts. There is only one main discharge at the control gap per half-cycle of the 60-cycle circuit.

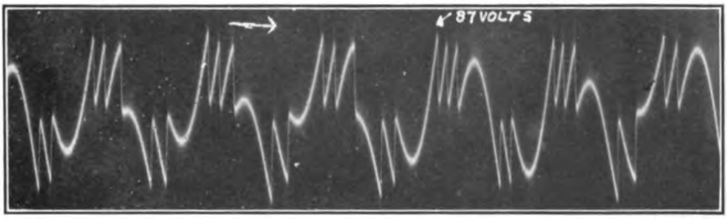


FIG. 5 [CREIGHTON]

Oscillogram of the voltage on the 110-volt side of the 60-cycle transformer. A blast of air was playing on the arc which removed the ionized gases and thereby introduced about three wave trains per half-cycle, all of which are about equal.

Comparing oscillograms of Fig. 3 and Fig. 4, it is seen that the voltage at the control gap may be reduced more than 50 per cent by decreasing the length of the control gap without increasing the number of wave trains per second which are effective in producing the high voltage on the secondary of the coreless transformer. In a 60-cycle circuit there are 120 alternations per second and the gap should spark over at each peak value of the 60-cycle potential. When the gap sparks over it is indicated on the oscillogram by a sudden drop. In Fig. 4 there are extra oscillations after the first peak value which re-light the spark but the voltage is so low, as compared to the peak value, that it is negligible.

In Fig. 5 an air blast is added which carried the ionized gases of the spark away and causes the voltage to rise to practically full value two or three times per half-cycle. The spark at the control gap is then extinguished and the voltage curve gradually drops into the regular 60-cycle wave, the distortion being due to the electromagnetic energy derived from the series reactance in the 60-cycle circuit.

11. Measurement of Voltage

The only available, practical method of measuring the voltage of high frequency wave trains is by sphere gap. Although the voltage may not be accurately expressed in volts, due to the unknown conditions of ionization and deionization at high frequency, and also due somewhat to the inevitable dielectrical spark lag, still there is no reason for not accepting the voltage measurement taken by the sphere gap. Since this statement may be open to question a further analysis of the object we have in view and how it differs from other voltage measurements is given in an endeavor to clarify the situation. Under the ordinary conditions of power distribution for lighting it is quite essential to have a definite voltage which can be measured and relied upon in order not to damage the lamps to which the voltage is applied or to have the voltage so low as to get an insufficient amount of light. The object in view in measuring the high frequency wave trains is not in any way similar. Therefore we do not need to have the same standard. The object in the measurement of the voltage, or more accurately stated, the equivalent sphere gap, of an insulator is the desire to know what potentials must exist at the terminals of the insulator to cause it to arc over or puncture. Although it would be of interest to express this tendency to spark over the insulator in terms of accurately expressed voltage, either peak value or effective value, it is not at all essential. The essential feature is to have a standard of reference with which to compare different types of insulators, different forms and conditions of electrodes, and such other features of design as produce the most reliable insulator. The sphere gap furnishes reliable means of measuring the limiting condition which will cause a spark to form over the insulator, and it is convenient to express the gap length in terms of the voltage which will cause the gap to arc over at the usual frequency of 60 cycles.

In choosing the sphere gap the diameter of the sphere is made about equal to the maximum gap length to be used.

There is another value of voltage that it is desirable to measure for the information it gives relative to lightning arresters; that is the minimum gap setting of the spheres which will take all the discharge away from the insulator. This minimum gap setting, is considerably below the maximum gap setting which causes practically all the discharges to take place across the insulator. The intermediate values of sphere gap settings between the maximum and minimum are in general of no particular interest.

Instead of giving the equivalent sphere gap in centimeters or inches the values are translated immediately by means of the scale on the oscillator into equivalent kilovolts at 60 cycles. In some cases we have used a straight scale subdivided into kilovolts underneath the supporting rod of the grounded sphere. In another case we have attached a wire to the shank of the grounded sphere and passed this wire around a cam which carried a pointer around a circular dial as shown in Fig. 1. The large dial adds little to the expense but it has the advantage of being read more easily and is economical of time in testing.

For special conditions of study a dial has also been used on the control gap which measures the gap length. The ratio between the voltage on the control gap and the voltage produced on the sphere gaps will vary according to the load that is placed in parallel with the sphere gaps. However, for any fixed condition of load the control gap can be calibrated and used as a measure of the applied potential with a fair degree of accuracy. The control gap gives the maximum voltage generated and the sphere gap gives the maximum voltage that exists across the insulator, which is naturally less than the maximum super-spark voltage applied. The voltage measured by the sphere gap is somewhat above the spark voltage of the insulator when the voltage is gradually increased in the usual way. The dial then on the control gap has its special uses although it is not an essential part of the testing outfit for the usual tests that have been made on insulators in the past.

12. Kilovolt-Ampere Capacity of the Oscillator

The kilovolt-ampere capacity of the testing apparatus is important especially where a number of insulators are tested in multiple. The capacitance of the electrostatic condenser used with the coreless transformer, together with the inductance and regulation of the coreless transformer, determines the value of power which can be delivered by the testing outfit. The power of the oscillator is used up in producing corona over the surface of the insulator and its connecting wire. In the oscillator testing set designed for general use, there is sufficient energy to produce spark-over on five disk insulators in parallel when the electrostatic condenser has a capacitance sufficient to store up 500 microcoulombs. By doubling the capacitance it is possible to test ten suspension type insulators in parallel. The rating of this oscillator is 125 kv. which it can carry continuously. For short periods of testing it has been used up to 175 kv. on a single insulator. It is capable of producing for an instant approximately 5000 kv-a. A somewhat smaller outfit could be used for testing single insulators of the suspension type but the smaller oscillator would have less application and would require a considerable knowledge of its characteristics and adaptability to prevent its being used under conditions which would give inadequate potential stress on the insulator.

We have in the laboratory an old Tesla coil outfit which is smaller, but the kilovolt-ampere capacity of this outfit was insufficient to spark over an insulator designed for 33-kv. circuit. The corona, formed at the head of the insulator and extending out about an inch over the surface, absorbed all the available energy from this outfit far below arc-over voltage.

13. What can be Done with the Oscillator to Reproduce Operating Conditions of Insulators

The ideal criterion for testing is to weed out all insulators which will fail subsequently in use. Tests should be made to meet these operating conditions. The method of test using the oscillator adapts itself with a fair degree of perfection to the reproduction of all of these conditions and it is only a matter of choice on the part of the engineer to get with its use the mildest or nearly the severest conditions of electric surges. These different degrees of severity of test can be obtained with greater ease and simplicity than with the 60-cycle testing apparatus. There is needed no special motor generator set, no fussing about sine-wave alternators, no question of limited kilowatt capacity due to the use of more or less resistance, no large transformer and separate means of excitation of the generator, etc. Two turns on the screw of the control gap give the full range of voltage, the maximum of which may be far above the arc-over voltage of the insulator and yet no short-circuit is produced on the oscillation transformer, such as takes place in the 60-cycle transformer when a spark occurs. The other factor involved in the tests is the duration of application which can, of course, be fully controlled by a hand switch.

14. TESTS WITH THE OSCILLATOR WITH SIX GRADATIONS OF SEVERITY AND DURATION

A number of arbitrarily chosen tests graded in severity and time of application, which corresponds to surge condition in practise, are given below for illustrations.

The first gradation, the mildest test with the oscillation transformer, consists in opening the control gap gradually until a slight corona appears on the insulator but keeping the applied high-frequency potential considerably below the value which will cause a spark around the skirts of the insulator. The corona is plentiful, audible, and visible in daylight, and therefore there is no difficulty in arriving at the desired degree. If this potential is applied for a very brief time it corresponds to a light induced discharge of lightning on the line, surges from switching, and the momentary arcing ground through enough resistance to prevent high potentials. This test is too mild to have any value except when the insulator is cracked or punctured.

The second gradation of testing is the application of this potential (somewhat less than the spark potential of the insulator) during a long period of time—say from one minute to five minutes. This test corresponds to a mild condition of sustained arcing ground. Insulators that will not stand this test would surely fail in service. The test is also too mild to consider for practical use.

The third gradation is obtained by opening the control gap of the oscillator so that the potential rises to a value sufficient to occasionally spark around the insulator—say once every second or so. Again this discharge may be applied for a fraction of a second corresponding to dangerous lightning discharges, dangerous surges from switching and from momentary arcing grounds.

The fourth gradation consists in applying this discharge for a longer time, ranging from one second to five minutes, which corresponds to high frequency surges generated by unusual conditions of vicious arcing grounds for a period corresponding to the duration of test. Such arcing grounds may or may not cause a short-circuit which ends the application of high voltage. Applied for one second, the test corresponds to 120 lightning strokes in quick succession of a voltage equal to the arc-over voltage of the insulator or some lesser unknown number of strokes scattered over several years. The test is very mild as a substitute for lightning strokes, as they come, of various values of potential above the value which is necessary to cause a spark around the skirts of the insulator. A duration of one minute makes a fair test and is recommended as a tentative standard.

The fifth gradation consists in opening up the control gap of the oscillation transformer so that momentarily the oscillation transformer gives its maximum voltage which should be a super-spark potential for the insulator. This voltage stress is applied to the porcelain during the brief time of dielectric spark lag that is required to form the spark around the skirts of the insulator or, otherwise, during the time necessary to puncture the porcelain. This test, applied momentarily, corresponds to a very heavy lightning discharge. It corresponds also to a rare case of switching and also to the accidental conditions where there is a cross between a high-voltage circuit and one of lower voltage. The application of a number of these single strokes is nothing more than the insulator may get in operation in due time. The surge potential corresponding to this test may not appear many times per year on a transmission system. Good continuous service suggests the test. Scarcity of good line insulators may not always permit the adoption of this as a commercial test.

The sixth gradation consists in applying this super-spark potential to the insulator for a longer period of time, of the order of 1 to 20 seconds. This latter test may very justifiably be considered from a conservative standpoint as more severe than is necessary, more severe than actually occurs as a rule in practise. It may, therefore, in the present state of development of insulators, be considered only as a comparative test to give the endurance of different types of insulators and may, consequently, be placed in the category known as a "design test."

15. TENTATIVE RECOMMENDED TESTS

There are special tests of unusual severity which it may be desirable to make as comparative between different types of insulators but with these special tests we are not concerned at the present moment. After testing many insulators the following test has been adopted for the purposes of this investigation. Raise the potential rapidly about two kv. every five seconds until an occasional spark is produced around the skirts of the insulator, a spark about every second or so; hold this potential for one minute; then raise the potential by about 20 per cent causing a flood of sparks around the insulator and hold for ten seconds.

16. OPERATORS' VIEWPOINT AND EXPERIENCE

Mr. F. Osgood at the recent meeting of the Institute emphasized very strongly that the oscillator had shown bad designs of insulators on their system, resulting in the complete elimination of all the insulators of a certain type, and furthermore, he found weakness in all the older pin types of porcelain insulators. The manufacturers of insulators were asked to produce an insulator which would stand the high-frequency test and I understand they have been able to do it. This is a step toward perfecting the insulation of a transmission line.

17. WHEN IS THE OSCILLATOR TEST DANGEROUS TO PORCELAIN?

In answer to the criticism that the method of test is dangerous, it should be noted that the surges on the line are also dangerous to the porcelain, especially if it is faulty.

The object of the test is to make it dangerous to faulty porcelain. The object should be, and before long will be, to damage and destroy every insulator which in practise would be damaged by the surges in the circuits. It will finally be good economy to do this. If the test is made to correspond to the conditions on the circuit against which the porcelain is designed to resist, then the statement of danger has only a desirable significance.

18. Recommendations

Let us examine the subject in its several different aspects: 1st, old designs; 2nd, cracked, porous, or punctured porcelain of insulators already installed; 3rd, new insulators not yet installed.

First. We have not yet arrived at a condition of perfection of design of all pin insulators. Therefore, it is too early to recommend a wholesale slaughter of weak designs. Reasonable engineering judgment must be exercised in each system to weed out the insulators which are weak enough to fail under the *frequently* occurring surges of switching and accidental arcs; but the next better grade should not be damaged by too severe tests and should be left in place on the lines to run chances in escaping a heavy strain due to lightning, until the evolution of design and manufacture brings forth a more perfect insulator. The test of these old insulators in place should therefore be milder than it will eventually be desirable to make it. It is not difficult to get a conception of the possibility of damaging an insulator under test. A time test, as described later, made on a number of insulators will determine the possibilities of damage from the test.

If old insulators are mounted on wooden cross-arms and the pins are not grounded a much weaker insulator can be used successfully than where the pin is grounded. Still the cracked and punctured porcelains must be removed from the circuit, because a failure of the insulator causes the destruction of the supporting wood and is consequently a great menace which threatens long continued interruption of service while a pole and arm are being replaced.

Second. In the case of porous or cracked or otherwise badly weakened porcelain the test must be severe enough to show the fault.

Third. In the purchase of new insulators the requirements of test should be severe enough to show faulty design and the presence of flaws which will subsequently be developed by the surges under service conditions. Rigorous tests should be used on new insulators before installation to determine definitely that neither the design nor the quality of porcelain is poor.

19. Is the High-Frequency Test Dangerous To Good Porcelain?

The next question relates to the danger of the test to good porcelain. Every test which carries the electric strain up to the maximum limit of the porcelain is very liable to cause danger even to good porcelain. If, as it should be, the thickness of porcelain is made such that the spark potential around the skirt is very much less than the puncture potential and the design is so made that the potential gradient at any point has a reasonable value, less than the damaging value, then the recommended high frequency tests can be made without damaging good porcelain. If many insulators fail it may be an indication that they are too near the danger limit of electric stress. In further reply to this criticism, it should be recalled that the results of tests on 60 cycles have shown that the 60-cycle potential at spark-over value may also damage porcelain.

In a paper presented to the A. I. E. E. June 1911 by Mr. Austin, he showed that the 60-cycle potential applied to a rack of insulators would puncture quite a number of them during the first period of a few minutes and would continue to puncture insulators during every minute that the test was continued although at a lesser number per minute as time went on. From this it is evident that at the end of a minute test there will necessarily be some porcelain insulators which are just ready to puncture and may be in a condition described as damaged. Familiarity with the rule of one minute duration of test may cause the critic to overlook this condition. The subject will be somewhat clarified by the observations on the nature of flaws given later.

Since 1911 there has been very evident progress made in the manufacture of electrical porcelain. From our observations on the use of high frequency potentials for testing insulators it would appear that defective insulators would be picked out earlier by the high frequency tests and our test results show that batches of suspension insulators delivered to the laboratory have withstood high frequency tests by the hour without losing a single insulator among them. Some tests were run continuously nine hours per day for six days with the voltage at barely arc-over value, and the insulators are still in good condition. This experience tends to show that only the faulty insulators will be picked out by the tests.

This question of damage to good porcelain in particular cases can be determined sometimes by special tests on insulators. If an insulator is tested continuously for an hour without puncturing, it is reasonably evident that a one-minute test will not damage the same porcelain and a test limited to a few seconds gives still further assurance. The question then of the duration of test and the damage that results thereby can be determined on special lots of insulators by the number that are damaged in a given time, which should be made long as compared to the standardized duration of test. Our own results show that an insulator of good design and good porcelain will withstand high-frequency discharge many hours. In thus comparing two different designs of insulators or two different makes of insulators, it is evident that one that withstands the discharge for the longest time will be the better insulator to use. If many insulators under test are shown to be damaged by a reasonable test it is evident that the design is faulty or the porcelain defective. If the test is made less severe than reasonable, then poor insulators will be installed on the line. With poor insulators installed, it becomes a matter of chance before they are caught by a surge. On the ideal line there should not be used a single insulator that will puncture.

20. Porcelain is not Heated by Normal Test with the Oscillator

A criticism of the method has been that the high frequency entails dielectric losses which it is feared will damage the porcelain There is no doubt that the high-frequency test produced more heat in the porcelain, by some sort of hysteretic effect, than comes from the application of 60-cycles. There is also no doubt that the high frequency will reach and damage a bad spot much more quickly and much more surely than the 60-cycle tests. In regard to this heating, however, there should be no confusion between the application of high frequency wave trains at 300,000 cycles from an oscillator and high frequency from a generator. In the case of the oscillator a wave train of high frequency is applied about 120 times per second. Between adjacent trains there is a relatively long period of rest, about 100 times the duration of a train, during which no potential is applied to the insulator. On the other hand, when the potential is supplied by a high frequency generator, the high frequency is absolutely continuous and the heating of the porcelain is correspondingly magnified. With continuous high-frequency voltage it is possible to overheat the insulator and damage it by heat alone. Even under continuous frequency nearly all the heat comes from corona in the air and very little from dielectric hysteresis in the porcelain.

In conclusion, long-continued tests have shown that there is no danger of hysteretic heating of good porcelain insulators by the recommended tests using the wave trains of an oscillator.

21. HEATING OF THE SURFACE OF THE INSULATOR BY CORONA AND SPARKS

As to the damage from heating the surface of the porcelain it can be stated in general that the corona may take place over periods of several minutes without heating up the porcelain more than a few degrees. It is hardly perceptible to the touch. The sparks have more heating effect but nothing serious—a rise of a few degrees. There is one undesirable condition, however, which will be perfectly evident to the tester: When, due to using very heavy discharges, the spark concentrates in one fixed streak around the porcelain skirts, local heating can take place on the surface of the porcelain. This concentrated heat will usually crack the porcelain in a minute or so. This fixed spark is an improper application and can be avoided by changing the conditions of test. It should be understood that the proper testing of the insulator by high frequency consists in making the discharge take a new path around the insulator at each successive discharge, so that the appearance to the eye is that of many radial streaks of discharge fairly uniformly distributed over the whole surface of the insulator.

TESTS RECOMMENDED

In the foregoing, flexible methods of tests have been laid out and criticisms of the test answered. Appended hereto it is hoped to add brief definite specifications for a fair set of tests. There is a very great advantage to be gained in the extensions of electrical transmissions by an improvement in the insulator. It is desirable that every important transmission company should have an oscillator testing set to be carried along the circuits to eliminate the insulators which are intrinsically poor in design and manufacture, and in addition, those which have been damaged either by expansion of the metal parts against the hard cement or by some crystallization effect in the cement which makes it expand. Factory testing does not meet the demand that not a single faulty insulator should be installed or operated on a transmission circuit, because the insulator may be damaged in transit or by some effect which develops in the course of time. This calls for testing on the ground.

22. CHARACTERISTICS OF THE 125-KV. HIGH-FREQUENCY OSCILLATOR

Much of the detail work of making a practical design of oscillator has been done by Mr. P. E. Hosegood. There are certain complex phases of the problems involved which are out of the scope of the present presentation. However, the important characteristics of the oscillator from a useful standpoint have been summarized by Mr. Hosegood and are herewith presented with the additions of only an occasional comment by the writer intended to connect the information with the rest of the paper.

One of the chief objects to be achieved in the design of a high-frequency oscillator for testing insulators is good regulation so as to be able to test a number of insulators at once without undue drop of voltage. When insulators are connected to the oscillator the voltage falls off due to regulation. The current in the high-voltage coil supplies two conditions, viz: the loss of energy in brush discharge and the capacitance of the insulators. These conditions call for as close a coupling between the two coils of the oscillator as can be obtained. Owing to the variation of the capacitance of the high-tension circuit of the oscillator, with varying loads, it is impracticable, in general work to use loose coupling between primary and secondary, and depend on adjusting the inductance and capacitance for resonance. With close coupling, the voltage generated at the high-tension terminal of the oscillator will depend chiefly on the ratio of turns between primary and secondary windings of the coreless transformer.

The voltage applied to the condenser depends upon the setting of the control gap. The preferred form of control gap consists of two wheels rotated by a motor. The spark takes place between the peripheries of the two wheels. This arrangement reduced the wear caused by the spark and also maintains the spark potential at a constant value for any given length of spark gap.

Figs. 3 and 4 show oscillograms of the potential across the 110-volt primary of the 60-cycle transformer. In Fig. 1 the control gap is set for 6000 volts effective, and in Fig. 2 for 12,000 volts. The latter is the maximum rating of the condenser. It will be noticed in both cases there is only one high-voltage spark for every half-cycle. When the spark takes place, it short-circuits the high-voltage side of the 60-cycle transformer, and a sudden decrease in voltage across the primary occurs. The primary source of power is not short-circuited but the voltage is momentarily shifted from the 60-cycle transformer to the series reactance shown in Fig. 2. It is only at very low settings on the control gap that the number of wave trains per half-cycle of the 60-cycle circuit increases materially. At low voltage it makes comparatively little difference in the effects obtained if the number of wave trains per second does increase.

In Fig. 5 an air blast is applied to the control gap which was set at 6000 volts. Two or three full-voltage sparks occurred every half-cycle. This materially increases the average current in the oscillator. With the air blast playing on the gap the number of sparks per half-cycle vary according to the length of control gap.

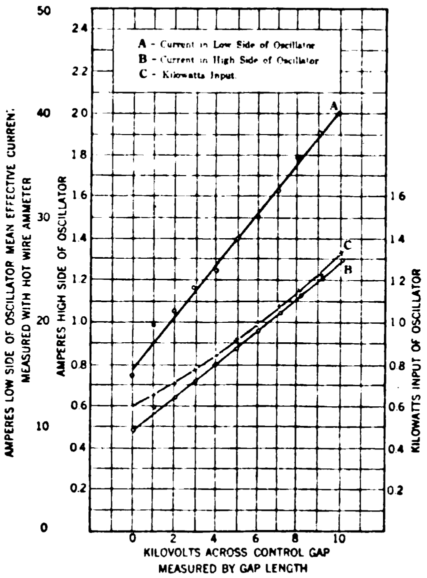


FIG. 6

Shirt-circuit characteristics of a 125-kv. oscillator. Top curve (A) is the relation of kilovolts across the control gap versus the effective current in the low side of the coreless transformer when the high side of the coreless transformer is short-circuited. Bottom curve (B) is the relation of the kilovolts across the control gap versus effective amperes on the high side of the coreless transformer. The current was measured by hot-wire meter. The middle curve (C) is the relation of the kilovolts across the control gap versus the kilowatt input of the oscillator measured on the 60-cycle side.

The curves of Fig. 6 give a measure of the oscillating currents in the high and low-tension coils of the oscillator at various settings of the control gap, the high-tension coil of the coreless transformer being short-circuited. The values of the control gap were obtained by calibrating the gap with 60-cycle voltage. The values of current increase with the control gap. This increase is not directly proportional, as the resistance of the spark increases with the length of control gap, causing more rapid damping of the oscillations of each wave train.

The no-load characteristic is shown in Fig. 7, curve *A*. The normal voltage rating of the oscillator, 125 kv., is obtained at no-load with a control gap setting of 5 kv. which is less than half the available voltage. Curves *B*, *C*, *D*, *E*, and *F* were taken with varying numbers of suspension type insulators connected in parallel to the terminals of the oscillator. With only one insulator connected, the arc-over voltage of the insulator is 85 kv. This arc-over voltage decreases when more insulators are added in parallel, due no doubt to the combined effects of the local oscillations coming from the corona on the surfaces of the parallel insulators and the difference in the arc-over volt-

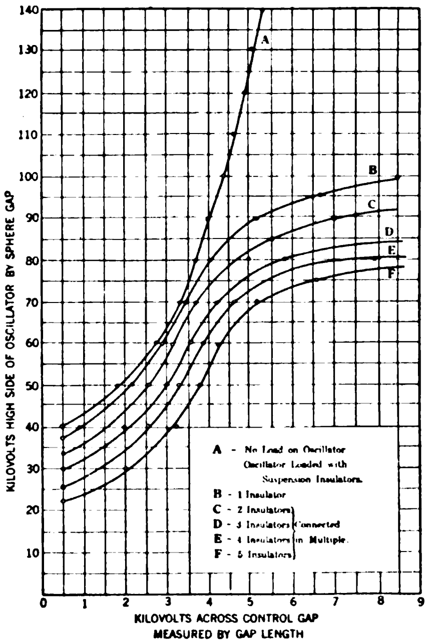


FIG. 7

Voltage generated by the 125-kv. oscillator in terms of control gap setting. Top curve (A), no load on the coreless transformer. Second curve (B), load of one suspension insulator. The third curve (C), load of two suspension insulators in multiple. The fourth curve (D), load of three suspension insulators in multiple. Fifth curve (E), four suspension insulators in multiple. Sixth curve (F), five suspension insulators in multiple.

age of the several insulators. With five insulators, the arc-over voltage measured by the sphere gap was 77 kv. These curves are practically parallel, and their different locations are due to the change of voltage ratio of the coreless transformer caused by the capacitance and corona at the insulators.

The effect of this load on the regulation of the oscillator is illustrated in Fig. 8, which shows the voltage obtained with varying numbers of insulators connected to the oscillator while maintaining the control gap constant. The voltage drop amounts to about 40 per cent from no-load to full-load, five insulators corresponding to full load for the condenser used in the oscillator.

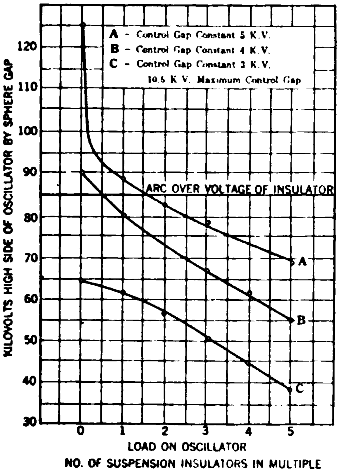


FIG. 8

Voltage regulation for variable loads with three different settings of the control gap on the 125-kv. oscillator. In the first curve (A) the control gap was held constant on a setting of 5 kv. and the load was increased from no insulators to five suspension insulators in multiple. At the addition of the second insulator the voltage was reduced slightly below the arc-over voltage of the insulator. Curve B is for a 4-kv. setting of the control gap, curve C for a 3-kv. setting. The maximum possible setting of the control gap in this oscillator is 10.5 kv.

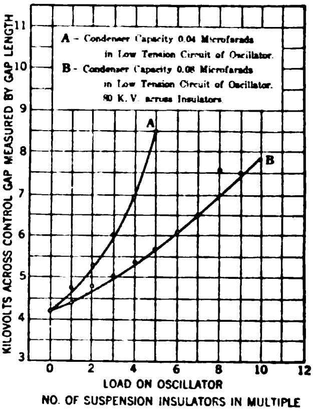


FIG. 9

Curves showing the gain in kilowatt capacity by increasing the capacitance of the condenser in a 125-kv. oscillator. Curve B shows that the load can be practically doubled by doubling the capacitance to 0.08 mf. There was generated constantly for all values of load and control gap, a voltage of 80 kv. across the insulators. This is slightly below the arc-over voltage of the insulator but sufficient to give extremely heavy corona.

The number of insulators that can be tested in multiple is directly proportional to the capacitance of the condenser in the low-tension circuit of the oscillator. This is illustrated in Fig. 9. By doubling the capacitance, the number of insulators that can be tested is increased from five to ten. The addition of capacitance to the oscillator lowers the frequency so that the output of the oscillator is limited by the minimum permissible frequency. The output can also be increased by raising the voltage applied to the condenser. However, the voltage necessarily increases more rapidly than the number of insulators that can be tested so that the more efficient way to increase the output of the oscillator is to increase the capacitance of the condensers.

Fig. 10 shows the load curve for the 125-kv. oscillator, with the insulators connected in multiple in strings of two in series. The control gap was set at 16.5 kv., which is beyond the rating of the condenser supplied with the standard outfit. In addition, an air blast of about ¾ of a pound per square inch was used. The regulation in this case was 18 per cent drop from no-load to a load of 16 insulators. The current supplied to the insulators was measured with a hot-wire ammeter. This current increases with the number of strings of insulators added, about 50 milliamperes for each string added. The input of the low-frequency transformer was measured and remained constant at two kw.

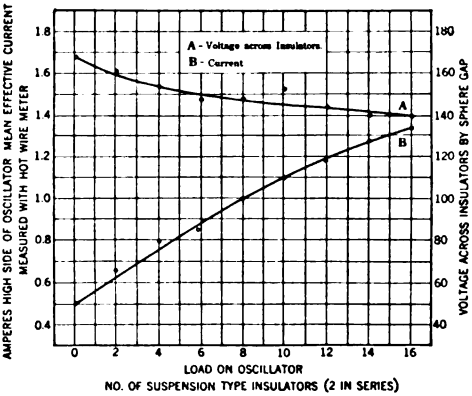


Fig. 10

In these curves the control gap was set at a constant value of 16.5 kv. with an air blast playing on it. It is an abnormal condition for the 125-kv. oscillator.

The load on the oscillator consisted of two suspension insulators in series and adding these as units. By so doing higher voltage was available than when one disk alone was used. The upper curve shows the decrease in voltage on the insulators as the load is increased. The lower curve shows the increase in current in the insulators due to the high-frequency wave trains as the load is increased.

24. Natural Frequency of the Oscillator

The frequency of the wave trains in the low-tension circuit of the coreless transformer, having the secondary coil removed, was measured with a cymometer. The search coil of the cymometer was loosely coupled electromagnetically with the low-tension circuit of the coreless transformer. The capacitance of the cymometer was then varied until the maximum voltage was obtained which was indicated by a small lamp. This frequency is 220,000 cycles per second. The high-tension coil of the coreless transformer was then replaced and the sphere gap opened beyond the value which would allow a discharge to take place. The two frequencies of a close coupled circuit were then obtained which were 238,000 and 508,000 cycles per second. With a load of five insulators on the oscillator only one frequency could be detected which was 360,000 cycles per second. The reduction in maximum frequency from 508,000 cycles per second to 360,000 cycles has apparently no practical bearing on testing. If the higher frequency were prominent it should lower the spark voltage. As a matter of fact it has just been shown that the contrary condition exists, increasing the load lowers the equivalent sphere gap.

Setting aside the possible effects of local surges between the parallel insulators, the change in natural frequency, as measured by the cymometer, has the effect, if any, of having increased from the minimum value of 238,000 to 360,000 cycles per second. There is no question at issue at present in this matter of frequency and voltage measurement. It is admitted that the theoretical problems, as a whole, are complex. There is involved dielectric spark lag for jump sparks and creepage sparks, and a consideration of each as it is affected by frequency, wave front, logarithmic decrement, energy in the corona, potential gradient, etc. All of these things are beside the point and beyond the scope of this paper. The same problems apply to 60-cycle circuits but the advocates of 60-cycle testing of insulators do not bring them into the discussion. The point is this: we are not directly concerned with the voltage which causes an insulator on a line to fail and thereby interrupt the service and damage the apparatus. The insulator must not fail. An insulator may pass a 60-cycle test but fail on a spark-over test from the oscillator. They are probably never strained in use on the line with a voltage at 60-cycles because their factor of safety places the operating voltage at a relatively small fraction of the arc-over voltage. When they are strained by voltage it is a high-frequency impulse or wave train very similar in form and natural frequency to the wave trains generated by

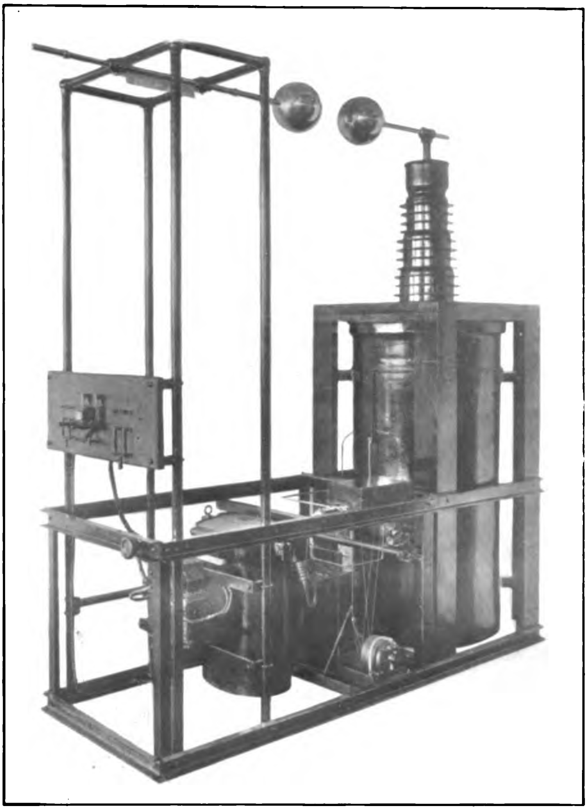


FIG. 11 [CREIGHTON]

The 250-kv. high-frequency oscillator. A small switchboard is mounted on the frame of the grounded sphere. Just below is a wheel for regulating the control gap. Above is the scale giving the value of kilovolts for the different settings of the sphere. Back of the corner post is the series reactance. To the right is the 60-cycle transformer. Still further to the right in the foreground is a small motor belted to the revolving wheels of the control gap. Back of the motor are the electrostatic condensers and to the right is a large coreless transformer supporting one sphere and having its other terminal grounded.

the oscillator. The wave trains in a transmission circuit will vary over a wide range of frequency but they will not differ as much in frequency from the oscillator as they do from 60 cycles, by more than a thousand times.

25. 250-kv. High-Frequency Oscillator

The general appearance of this oscillator is shown in Fig. 11, the construction being similar to the 125-kv. oscillator. The coupling between the high- and low-tension coils of the coreless transformer, however, is not as close, as more insulation is necessary between coils. The short-circuit characteristics are shown in Fig. 12. These are similar to those obtained with the 125-kv. set. The effect of an air blast on the spark in the control-gap in increasing the current in the oscillator coils and the watts input, is shown in curves *D* and *E*. The current is increased about 40 per cent.

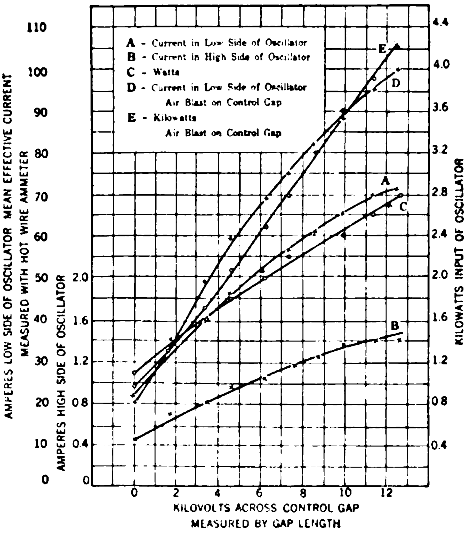


Fig. 12

Short-circuit characteristics of a 250-kv. high-frequency oscillator with the high side of the coreless transformer short-circuited. The following relations are given: Kilovolts across control gap versus current in low side of coreless transformer (Curve A). Kilovolts across control gap versus current in high side of coreless tranformer (Curve B). (Smaller values of ampere scale to the left.) Kilovolts across control gap versus kilowatt input of oscillator (Curve C). Scale to the right.

An air blast was then played on the spark in the control gap. Curve D corresponds to Curve A under this new condition. Also Curve E of the kilowatts with the air blast on corresponds to Curve C. It will be noted that the air blast increases both the current and kilowatt input by producing a greater number of wave trains, as illustrated in Fig. 5.

Fig. 13 shows the no-load characteristic. For small values of control-gap setting the air blast increases the voltage obtained on the high side of the oscillator. This is probably due to the cooling effect of the blast raising the spark potential of the control gap. For higher values of the control-gap setting this effect becomes less noticeable.

Curves *B* and *D* show the effect of connecting to the oscillator a 70-kv. oil-filled transformer bushing. These curves begin to bend over at about 230 kv. owing to the rapid increase of the brush discharge as the arc-over voltage of the bushings is approached. This arc-over voltage is about 245 kv.

PART II

26. The Manufacture of Electrical Porcelain

In the order in which the work described in this paper was done, various experiences in testing porcelain with the oscillator should come next, but to understand the results of the experiments a knowledge of the characteristics of porcelain in its various stages of manufacture is quite essential. Therefore the processes of manufacture will be mentioned before continuing with the experiences of testing.

The object of this part of the paper is to endeavor to bring together the elements of scientific ceramics as they relate to porcelain for electrical purposes, eliminating all products pertaining to various other industries.

The endeavor is to draw out of this mass of literature only the parts that seem to relate to porcelain for electrical purposes. The object is also to bring the subject of ceramics far enough into the field of electrical engineering to arouse an interest in the subject as it relates to our work. It is hoped to accomplish this by a cursory review of the subject, such as may be made in the time at my disposal, and in this review give references on the subject to the student who is desirous of making a further study into the details.

On the side of ceramic engineering it is hoped to stimulate a sufficient interest to obtain help and place the ceramic engineer in a better position to help himself by giving definite methods of electrical tests and making definite statements of our requirements of porcelain parts used as insulators. The natural aim is to improve the integrity of the insulators. Simply put, it is desirable to have an insulator which will never puncture nor break and if the potentials from lightning get beyond its dielectric strength the insulator must spark over through the air without puncturing the porcelain. To attain this end, many complex and unsolved problems must be considered. In this paper we are interested mostly in the problem of the production of a desirable insulator rather than in methods of protection which may be used to prevent high potentials occurring on an insulator.

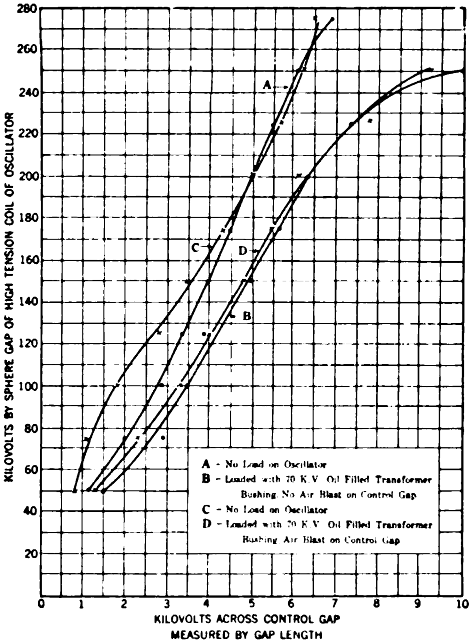


FIG. 13

The relation of kilovolts across the control gap to the kilovolts on the high-tension side of the coreless transformer as measured by sphere gap.

Curve A, no load on oscillator: Curve B, loaded with one 70-kv. oil-filled transformer bushing.

An air blast was then played on the spark of the control gap and curves C and D were taken. Curve C, no load on oscillator, as in Curve A. Curve D, same load as in Curve B. It will be noted that except at low values of control gap the air blast had very little effect on the voltage generated. In general, with the revolving wheels for control gap, the air blast will change the number of wave trains without changing materially the voltage.

27. DESIRABLE QUALITIES IN A PORCELAIN INSULATOR

1. It shall be mechanically strong in compression and tension.
2. It shall be tough, not brittle or fragile.
3. It shall be non-porous.
4. The porcelain shall be without appreciable cracks, laminations, cavities, conducting flaws, or air pockets.
5. It shall be of a fair, uniform dielectric strength.

6. It shall have a permanent glaze without cracks, roughness or checks to hold dirt in the surface. It is desirable to have the glaze as non-hydroscopic as it is possible to obtain without sacrificing other factors.

7. Incidentally the coefficient of expansion of the porcelain should be low in order to permit of sudden changes of temperature due to the weather conditions.

8. The parts should be held together with non-changeable cement.

9. In the matter of design the general rule to follow should be to keep the distance between the metal electrodes as great as the mechanical strength will permit. In general this rule calls for thicker porcelain than can be economically manufactured.

10. The design should be such that the air around the insulator is weaker to puncture than the thickness of the porcelain even under super-spark potentials.

11. The design should be such as to give a relatively long drip space for water so as to hold a high value of spark-over potential during a rain.

12. For dusty countries extra lengths of creepage surface should be provided.

It is far easier to state what is desired than it is to make definite recommendations of how the desiderata are to be obtained. Every possible avenue of investigation should be tried until the desired perfection of insulator is reached.

28. Literature on Porcelain

Most of the literature on ceramics treats of pottery from an artistic and historic standpoint. One must read hours to pick up a few grains of useful information on the electrical porcelain intended for engineering purposes. One long book, containing over 700 pages on the manufacture of ceramic materials, devotes only one-half page to electrical porcelain. The Encyclopedia Britannica devotes many pages to what can be seen on the surface of some specimen handed down from the nations of antiquity. These specimens range in technical skill of manufacture from the sun-dried pot, through the grade of soft porcelain, and finally to the most difficult, namely the art porcelain composed of kaolin, or china clay.

The writers on porcelain have not yet recognized that the modern electrical porcelain involves more attention to the form of the parts than the most fastidious Greek ever gave his. If in the ancient Greek art the curves were poor it displeased some of the cultivated eyes,—that was all. If in modern electrical porcelain the curves are poor, thousands of people are deprived of light and power,—which might be conceded as a more serious matter.

Electrical porcelain is an art of the present decade,—an art in the making. The author has spent much time culling out of the massive literature on the civilization-old art some of the pertinent factors relating to electrical porcelain, and it is thought that such condensed information is of value to others who are interested but have not the time or opportunity to cover the subject.

While making tests under new advantageous conditions the information has been brought to the attention of ceramic engineers, and it is hoped, through this system of checking, that inaccuracies regarding the porcelain manufacture in any of the essential parts have been avoided. The difficulties of getting definite information on porcelain will be fully appreciated only by those who have tried. In our own meetings we have even been advised as electrical engineers to leave this difficult subject to the particular man who fires the porcelain part. For the electrical engineer a cloud of mystery is thrown around this work. The desire to maintain trade secrets has obscured processes which are universally used. Either a knowledge of some of these processes must be furnished to the electrical engineer to intelligently interpret his electrical tests, or else the ceramic engineer must fully master the electrical problem of design and produce the finished satisfactory insulators. One naturally turns to the Proceedings of the American Ceramic Society for information. In the Annual Report of the Board of Trustees the statement is made that, " Our industries are most of them old, and most of them have been and still are administered upon mistaken policy of secrecy as a necessary condition of success. Very few practical ceramic chemists and works managers will tell what they know of their own branch of the industry."

29. DRY PROCESS VERSUS WET PROCESS

Dry Process Porcelain. We are not concerned herein with all grades of electrical porcelain. Porcelain for electrical purposes is divided into two quite distinct grades, known as *dry process* and *wet process* porcelain. As indicated by the names, they differ in manufacture mostly in the way the porcelain pieces are formed into the desired shapes. In the dry process, the raw mixture is in the form of slightly moist granular particles containing about 20 per cent of moisture by weight. These moist particles having the appearance of granulated or grated cheese, are made to cohere in a moment into a handleable soft mass by being subjected to a high mechanical pressure in a mold. This pressure, no matter how great, does not squeeze out the entrapped air between the particles and furthermore, under the usual conditions of firing the open pores still remain. As a result, dry process porcelain is electrically only about equal to air in its dielectric strength. To get mechanical strength, the thickness of the porcelain parts is usually great enough to give safe dielectric strengths of the order of a thousand volts. When the voltage impressed on this porous dry process porcelain is several thousand volts the potential gradient at sharp corners of the electrodes is sufficient to start a molecular bombardment of the air in the pores. As a result the porcelain becomes heated, its ohmic resistance rapidly decreases with temperature and there is added to the heat of corona, the I^2R losses. If the dry process porcelain is used on high voltages it is used as a mechanical support but not as an insulator.

Wet Process Porcelain. The wet process porcelain is deposited in the form of a plastic cake, as will be described later, and although this cake becomes quite porous when it is dried out, the size of the pores, or the spacing between particles is much smaller than in the dry process piece; consequently these particles can be cemented together in the kiln by the flux when the temperature reaches the melting temperature of the flux. Looking at the condition from a slightly different standpoint, each grain of the dry process material is made up of many fine particles of the same size as in the wet process and each grain becomes fairly well cemented into a solid vitrified mass, but the separate grains of the dry process are vitrified together only in those touching points that are near enough together to be connected by the softened flux at high temperature. In the shrinkage many irregular masses are pulled slightly apart leaving not only open pores but open streaks which are easily observed with the naked eye by first soaking the porcelain piece in red ink, (or better still aniline stain in alcohol), and subsequently breaking the porcelain piece into fragments.

30. THE INGREDIENTS OF ELECTRICAL PORCELAIN

The three main ingredients of electrical porcelain are feldspar, clay and silica.

The feldspar constitute a large portion of granite rock. After the granite is crumbled a certain amount of free feldspar results. There are three feldspars which exist either separately or more or less mixed mechanically and chemically in the mines.

1. Potash feldspars, known also as common feldspar or the mineral orthoclase. It consists of potassium, aluminum, silicon, and oxygen. $K_2\ Al_2\ Si_6\ O_{16}$

2. Soda feldspars—a tersilicate of soda—a mineral known as albite or indianite. It contains sodium, aluminum, silicon, and oxygen. $Na_2\ Al_2\ Si_6\ O_{16}$

3. Lime feldspar or unisilicate of calcium—a mineral known as anorthite, consists of calcium, aluminum, silicon, and oxygen. $Ca\ Al_2Si_2O_8$. The most important of these three feldspars for electrical work is potash feldspar.

When the feldspars are disintegrated or separated into their respective constituent oxides they have the following chemical formulas and percentage of weight.

		Potash	Alumina	Silica
Potash Feldspar	Molecular properties	K_2O	Al_2O_3	$Si\ O_2$
	Percentage weight	16.9	18.4	64.7 = 100%
Soda Feldspar	Molecular properties	Na_2O	Al_2O_3	$Si\ O_2$
	Percentage weight	11.8%	19.6%	68.6 = 100%
Lime Feldspar	Molecular properties	$Ca\ O$	Al_2O_3	$2\ SI\ O_2$
	Percentage weight	20.1%	36.8%	43.1 = 100%

CLAYS

The two clays used as main constituents of porcelain are ball clay, and china clay or kaolin. The chemical analyses given of the clays differ from each other very little yet the properties or characteristics of these clays in the practical work of manufacture differ greatly.

The important physical quality which distinguishes the clays is their degrees of plasticity. The physical and chemical conditions which give the clays their plasticity seems to be a mooted question still among the ceramists. The particles of clay are exceedingly small. They are sometimes spoken of as colloids. The plastic clay has an unctuous greasy feel when rubbed.

Although the cause of plasticity cannot be given, the quality itself is familiar. By plasticity, as used by ceramists, something more is meant than that quality of allowing a change of dimensions by kneading while maintaining the particles in cohesion such as exhibited by light bread dough. There is meant or implied that after the water, mixed with the clay to render it plastic and pliable, is dried out, the particles of clay will not crumble into dust but will remain in a sufficiently solid condition to be handled without breakage. A variation in the relative weights of water is needed to render the clays from the several different mines plastic. The china clays and kaolins have not a high degree of plasticity and therefore there is added to them ball clay which has the highest degree of plasticity. A piece of soft ball clay can be rolled into a long round coherent thread or rope without breaking. After the raw porcelain is dry it must retain sufficient coherence not only to hold itself together but also the ground up particles of feldspar and flint, neither of which possess sufficient plasticity to give much aid. All the clays lose their plasticity after being heated above a few hundred degrees centigrade. It should be recognized that plasticity and coherence are among the most important qualities of raw porcelain. Many of the flaws are developed in an incipient degree before the porcelain goes to kiln.

The word kaolin is a corruption of a Chinese name for the locality where the china clay was obtained for the ancient industries. Kaolin, the clay, has an essential ingredient the mineral kaolinite. The formula for kaolinite is given in several forms. It seems evident that the molecular structure varies greatly according to the material from which the kaolinite was formed.

Kaolinite is composed of hydrogen, aluminum, silicon, oxygen, and water of composition. The chemical formula is written as follows: $H_2Al_2Si_2O_8 + 1H_2O$.

When the kaolinite is considered from the standpoint of the resulting product, after it is disintegrated, its composition is given in terms of its oxides, namely alumina, silica, and water, in the formula Al_2O_3, 2 Si O_2, and 2 H_2O. The proportion of each of these is given in percentage directly below the corresponding formula.

	Alumina	Silica	Water
By formula....................	Al_2O_3	2 Si O_2	2 H_2O
By relative weight..............	39.8%	46.3%	13.9%

Kaolinite is derived from the disintegration of feldspar in granite rocks which is brought about by the action of the elements, air, water and temperature.

Granite consists of the minerals orthoclase or microcline, mica, and quartz.

Silica, SiO_2, silicon dioxid, silicic oxide, quartz, flint, crystalline silica and sand are all used synomymously in relation to porcelain manufacture. All of these materials are nearly pure silica in slightly different molecular form and different in the nature of their small impurities. In general this constituent of porcelain is called flint although in many porcelains ground-up quartz sand is used. Of the other silica materials which are not used but which are high in silica there is the precious stone opal which has a higher content of water, infusorial earth, and float stone.

If we turn to the chemistry on these three materials we learn that the feldspar is used as a flux on account of its content of potash or soda. Flint, and quartz alone are very refectory materials and are not affected by the temperature of 1350 deg. cent., the approximate value of the temperature of a porcelain kiln. Quartz is not attacked by acid with the exception of hydrofluoric. Boiling alkalin solutions scarcely affect it. Flint, however, dissolves more readily in boiling solutions of the alkalin hydroxides. All the varieties of silica, however, when heated to redness with the alkalis, such as potash K_2O or the alkaline carbonites, combine with the bases forming silicates which enter into fusion at a high temperature and solidify to a vitreous mass on cooling.

It is this solvent action of the potash of the feldspar on the quartz or flint which produces the solid porcelain mass. The greater the quantity of feldspar or flux the greater the tendency to vitrify. Combinations of clay and silica containing very little flux require extremely high temperatures to vitrify—several hundred degrees above the value usually obtained in the porcelain kiln. A definite idea of the softening temperature of the different compounds is furnished by the Seger cones which are used to measure the vitrifying condition in the kilns. These cones consist of the different minerals made up in a triangular pyramid, having a width of 9/16 in. at the base, 1/16 in. at the top and an over-all height of $2\frac{7}{8}$ in. The catalogue of the manufacture of the cones gives a complete list of ingredients with the corresponding temperatures they represent.

Several of these cones, Fig. 14, differing by one number, are placed side by side as a unit, and are located in different parts of the furnace where it is desired to measure the temperature. As the temperature reaches the melting point of each cone it deforms by bending over like a wilted plant. These cones under the high temperatures of the furnace droop to different degrees and the one that is not deformed at all represents the temperature or limit of the vitrifying tendency of the furnace.

To obtain a porcelain which will vitrify at different temperatures it is in general necessary only to change the content of potash or soda. It may be done also by using a feldspar containing both potash and soda in combination as the two together seem to have a greater solvent action than either one alone.

Lime feldspar is used not at all or only sparingly. Lime is one of the chief ingredients of common glass and apparently has undesirable qualities in porcelain.

31. THE PROPORTION OF DIFFERENT MINERALS FOR PORCELAIN AND THE DIFFICULTIES IN OBTAINING AND MAINTAINING THESE PROPORTIONS DUE TO THE GEOLOGICAL CONDITIONS AND METHODS OF MINING

A standard mixture for porcelain for testing purposes is given as feldspar 20 parts by weight, quartz 30 parts by weight, kaolin 50 parts by weight. In Bulletin 53 of the Government Bureau of Mines, Mr. A. S. Watts states that the role of kaolin in all pottery mixtures is that of a plastic bond. It continues to hold the material together through the drying process. In firing, the kaolin by its high refectory value and its resistance to the solvent action of the feldspar, enables the mass to retain its form although the particles of kaolin may be enveloped in fluid feldspar so completely that the mass becomes translucent and appears homogeneous.

The ingredients of porcelain as received in the mineral state by the porcelain manufacturers are liable to considerable variations both in their chemical contents and in the molecular form in which they exist. One cannot understand the difficulties of porcelain manufacture without a comprehension of the methods and conditions of mining the minerals. The change of material sold by the same name and giving the same chemical analysis in a porcelain factory is usually not carried out within a year after the change is contemplated as it requires a very long time to learn the methods of handling the new material

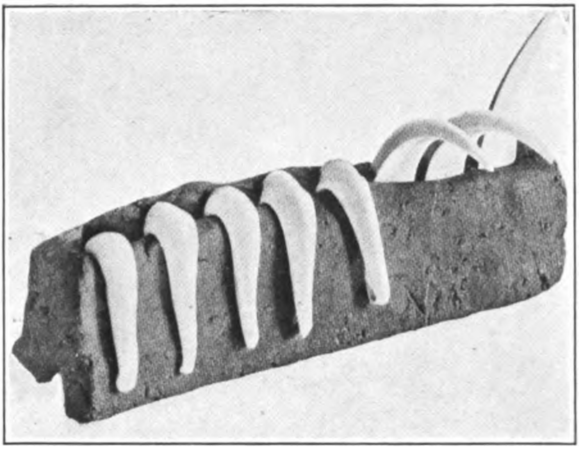


FIG. 14 [CREIGHTON]

Fired Seger cone showing the five lower cones entirely wilted, two cones part way down and one cone still standing almost vertical. (Bulletin 53. By courtesy of U. S. Department of the Interior.)

in the many different forms in which electrical porcelain parts are made. In Bulletin 53 on mining and treatment of feldspar and kaolin in the Southern Appalachian region, already mentioned, Mr. Watts devotes 170 pages to the study of this subject from many standpoints. He described deposits of feldspar which are in all grades of decomposition approaching kaolin. Before such material can be used it is necessary to separate the kaolin clay from the semi-kaolinized feldspar or otherwise it is necessary to have a uniform mixture which can be depended upon after the proper mixture of other clays and feldspar is determined by experimentation. There is always a considerable amount of silica in one form or another in these deposits of clay and there are more or less impurities such as oxides of magnesium, calcium and iron. There is often the mixture of minerals washed in from the surface during the time of mining and incidental deposits and streaks of other materials which have found their way into the mass during the time of their geological formation. Some of these foreign materials may be picked out in lumps by hand. There is usually present more or less mica. Indeed some of the mines are operated for the mica leaving the clays only as a by-product. The mica must be removed. The methods of refining the clays differ somewhat according to the nature of the deposits but the general plan followed is by separation by difference in weight of the particles. When the kaolin is formed by the decomposition of feldspar it apparently forms a colloid of extremely small diameter. This fact is utilized to separate the fine clay from the coarser quartz sand and feldspar by floating it in water. If a mass of this material is stirred up in water the heavier particles will immediately settle to the bottom and the lighter particles can be floated off. It is by means of these settlings and floatations in water that the fine clay is separated from the coarser materials and is finally dried and thus prepared for shipment. If there exists in this mechanical mixture small particles of flint or feldspar they are of course carried over with the fine clay. Screens are used to separate the mica. In the final concentrating tank there is sometimes introduced a floculator in the form of alum in order to hasten the settlings of the very fine clay particles.

With all these possibilities of impurities arising in the process of mining, with all the different molecular forms which this material may take and all the variations which may occur from one part of a mine to another, and with the impossibility of getting any chemical analysis in general on which a practical porcelain manufacturer can depend, it will be appreciated that the difficulties in getting and maintaining the proper mixtures in a porcelain factory are very great.

32. SOME OF THE SALIENT POINTS IN THE FACTORY PROCESS

The points in which we are interested in general are those which have a direct bearing on the final product as an insulator. After an examination of the dielectric strength of porcelain from four different manufacturers, all of which use different clays, and therefore vary in their chemical content to a certain extent, it would seen that within a considerable range, the minerals, as such, have little bearing on the dielectric strength. The minerals in regard to their ease of working and uniformity may have considerable to do with the final product in avoiding cracks, flaws, laminations, and other like mechanical accidents of manufacture.

A certain quantity of china clay, ball clay, fledspar, and flint are ground separately to impalpable powder and are weighed out and thorwn into a large tank, known as an agitator, in which there is a motor-driven paddle which constantly keeps the material mixed up. The liquid consisting of these fine particles suspended in the water, of the consistency of heavy cream, is known as "slip." There is the possibility of some slight difference in uniformity due to difference in weight of the particles and this is the first possibility of non-homogeneous material. A porcelain manufacturer states, however, that the probabilities are comparatively slight since all the material is made fine enough to pass through a certain size sieve—100 to 200 mesh per inch.

After being mixed in the agitator tank, the slip is pumped into filter presses in which the water is forced out through canvas, leaving the fine materials deposited in the form of soft wet cakes. In this deposition there is a tendency for the coarser material to segregate from the finer materials. Since this filter press is worked under considerable hydrostatic pressure and the fibres of the canvas must finally wear out, there will be occasionally here and there a fine cotton fibre which finds its way into the mass of clay. This fibre, carbonized in the firing, will form a ready path of puncture.

The cakes of deposited raw porcelain which come from the filter press are thrown in a pile and hammered down by a large mallet. This material is then sliced off by means of a thin wire having a wooden handle at each end and the pieces are thrown into a pug mill. Human hairs, threads, and other carbonacious substances occasionally find their way into the porcelain during this period and subsequently cause an electrical flaw.

The pug mill consists of a cylindrical receptacle about five feet high. In the center of this cylinder there is a vertical shaft from which extend horizontal arms or blades formed like the propeller of a boat. The blades cut through the plastic mass and constantly squeeze out the air and force the material downward. At the bottom is a horizontal opening, four to eight inches in diameter, out of which the soft mass is squirted by the pressure exerted by the blades above, or by an auger near the exit. It then has a consistency barely sufficient to hold its form. As this plastic mass comes from the pug mill it is cut off into cylindrical pieces by means of a fine wire. The proper manipulation of the material in the pug mill is considered of very great importance as it is possible to leave the clay in a condition in the pug mill which will subsequently cause a sufficient defect in a porcelain part to condemn it for practical use. The pug mill is used to remix the constituent parts so that the materials will be uniformly distributed through the entire mass. To obtain this end, it is sometimes necessary to put the raw porcelain through the pug mill more than once and, as an interesting incident, it is necessary to add more water to the mass each time it goes through, to replace the loss due to heating which results from the friction of the revolving blades against the plastic mass. Before the raw porcelain is thus mixed in the pug mill it is possible to pick out spots where even inexperienced persons can recognize non-homogeneous conditions by the feel and plasticity of the soft mass.

In the usual molded process the soft plastic mass as it comes from the pug mill is formed or "jiggered" into a "blank" of the approximate shape which it is finally to have and the "blank" is then left to partially dry. It is sometimes jiggered into a plaster paris mold. As the moisture evaporates from the surface the material shrinks to a certain extent and since the outer surface must always be drier than the central parts there must always exist a tendency for cracks to form on the surface. This is prevented by not having the plastic mold too dry, by keeping the design dimensions within reasonable limits, usually within an inch of thickness, and by controlling the moisture content in the atmosphere of the drying room. Where a drying room is full of fresh samples the humidity of the room is high and consequently the drying will be slow. In times of slack work where a less number of pieces are drying there will be more rapid drying and consequently a greater danger of damage through shrinkage. There will be a difference due to the humidity of the seasons.

When the material becomes fairly dry it should have sufficient strength to allow it to be handled in packing it in the saggers ready for firing and, in many cases, sufficiently strong to allow of turning in a lathe. Herein comes an important factor of plasticity and coherence in choosing the ingredients of the porcelain.

33. Glazing

After the porcelain pieces have become well air-dried they are glazed. The usual glaze consists of a material essentially the same as the porcelain except that a higher percentage of flux is used which makes the glaze melt and run over the surface at a temperature which barely vitrifies the body of the porcelain. The flux of the glaze unites with the porcelain body on the surface and forms a chemical combination which makes a gradation from pure glaze to pure porcelain.

The glaze is put on the surface by means of dipping. The fine material in water in the tank is often kept in suspension by means of a stirrer and the dry surface of the porcelain absorbs the water and thus produces a thin coating of the glaze material on the surface in a powdered form. The moisture thus introduced in the material is then allowed to dry out and if the whole surface of the porcelain has been glazed it is necessary to scratch off the powder of the glaze where the porcelain piece will rest on the sagger or otherwise the porcelain piece after firing would be glazed solidly to the sagger. The colors of the glazes are produced by different oxides.

In other kinds of pottery there are other glazes and other methods of glazing used which have no application to any of the electrical porcelains. In some of the earthenware materials glazing is produced by throwing common salt, NaCl, onto the red-hot material. The chlorin is given off and the free sodium combines with the earthenware material and thus forms a glaze. In some work known as biscuit porcelain, used especially in art work, the porcelain is given a preliminary firing at a high temperature with no glaze on it. It is subsequently covered with a glaze requiring a much lower temperature to melt it. Such a glaze will often have a difference of expansion relative to the porcelain body and there is, involved, therefore, a great tendency to check or crack, known technically as " crazing." Electrical porcelain, in general, is fired only once and glazed at that time or not at all.

34. FIRING

After the clay has been thoroughly air-dried and possibly baked to a temperature of 110 degrees to drive off all the free moisture it is packed in saggers which are yellowish, rough earthenware dishes, in the material of which there is a very small content of flux and therefore a much higher melting point than the porcelain parts which they contain. The usual saggers are cylindrical in form, a foot or two in diameter and high enough to accommodate the porcelain pieces. They are open at the top. These saggers containing the porcelain parts are stacked in the furnace one on top of another, making a column from the base of the furnace to the top. This column of saggers is called a bung. The furnace is completely filled with these bungs, leaving only room here and there above the many openings in the base of the kiln for the heat flames to rise as uniformly as possible through the entire mass. The usual kiln is bottle-shaped. Around its base at equal distances are eight fire-places which feed into a radial flue running to the center with several vertical openings into the kiln.

The fires are then started, using either a good grade of coal or gas, and the temperature is gradually brought up for hours to a value in the neighborhood of 1310 to 1360 deg. cent. After reaching the maximum temperature it is usual to hold the temperature for several hours in order to let the heat soak uniformly throughout the mass of bungs. The fires are then allowed to die out and the kiln cools, the whole process taking several days depending on the size of kiln. The fire brick door is knocked out, the saggers are unstacked and the porcelain parts taken out and examined for flaws. The porcelain parts which pass this visual inspection are then ready for the electrical tests.

35. A REVIEW OF THE PROCESSES OF PORCELAIN MANUFACTURE WHICH HAVE TO DO WITH THE DIELECTRIC STRENGTH OF THE PORCELAIN THE CHOICE OF INGREDIENTS AS AFFECTED BY FIRING

The firing temperature of a furnace is fixed by experience with a certain mixture of porcelain ingredients. It is assumed that each mix of this material is the same as the previous one on which the experience was obtained. Necessarily then whatever be the chemical contents of the bins marked china clay, ball clay, flint, and feldspar, this material should be uniform. If these materials vary in chemical composition there is no definite way of determining it until the firing is completed and all the damage is done. If the flux is too small in quantity the porcelain may be found under-fired and porous; on the other hand, if the flux is too great in quantity the porcelain parts may be over-vitrified and therefore brittle and they may even be warped entirely out of shape by becoming too soft. An important point in this regard seems to be to keep enough solid material in the form of either alumina contained in the clay or relatively large particles of flint so as to hold the body of the porcelain in form during the firing. The desire of the ceramist is to obtain a body and flux which will have a wide range of temperature between the lowest temperature which will cause a softening of the flux and the lowest temperature which will cause a warping of the porcelain due to its own weight. The initial ingredients are then of great practical importance to the ceramist in obtaining a useful article, when the firing is completed, both in form and dielectric strength. Porous porcelain will absorb moisture and will therefore have its insulating value greatly decreased. As already stated, there is always some surface on the porcelain piece which is not vitrified and it is through this surface that moisture may subsequently enter the whole body of porous porcelain. If the porcelain is over-vitrified it will be brittle and although its dielectric strength may be excellent it is liable to damage in shipment or installation due to its fragility.

36. Homogeneity of Structure in the Plastic Form

Assuming then a proper choice of the mixture, the next important step is the conditions of the pug mill. The material must be made thoroughly homogeneous when it leaves the pug mill. Otherwise there will be a separation into laminations or local spots that are not fully vitrified together. If many porcelain parts of irregular form are broken up after they have been punctured electrically laminations will frequently be found in the material. It is stated that some of these laminations really originated at the time the clay was passed through the pug mill. As the raw porcelain in flat cakes comes from the filter press it will frequently contain a layer of flint. This layer of flint lacks plasticity and if not thoroughly mixed with the ball clay in the pug mill the raw porcelain in drying will open in a lamination or crack at this surface of weak plasticity. Where the lamination is perpendicular to the lines of electric force very little weakening in the dielectric strength of the porcelain piece takes place, but where this lamination occurs at an angle or parallel to the lines of electric force the porcelain part usually lacks enough dielectric strength to make it useful.

37. Flaws Developed During the Process of Drying in Air

Occasionally it happens that changes of moisture in the atmosphere, especially in the dry season which is the winter time in the cold countries, will cause a shelf-full of drying porcelain or a few on the end of the shelf to dry with such great rapidity as to introduce local internal mechanical strains in the body of the solidifying material. It is therefore of great value to study the rate of change of plasticity and shrinkage at the different states of drying. Bourry (Treatise on Ceramic Industries—D. Van Nostrand Co.—) shows by the curves which follow that the greatest contraction takes place in the clay body at the time it is changing from a soft plastic condition to a solid form. Subsequently, although the moisture is still considerable, the shrinkage is very much less. It is therefore during the early stages of drying that the greatest care must be taken to prevent a rapid evaporation from the surface of the porcelain. Subsequently much less care need be taken and more haste is permissible.

38. Theory of Drying

Bourry divides the drying of raw porcelain into three periods. The plastic material consists of solid particles and water. The solid particles are all small but vary greatly in dimension from the very fine particles of clay to the coarsest particles of flint. Each one of these particles is surrounded by a film of water held in position by capillary attraction. This gives a certain fluidity or ease of movement of one particle over another and is one of the factors which accounts for plasticity. In this soft condition it can be stated that there is a certain definite volume of solid material and a certain volume of water. As the drying proceeds, the film of water between particles becomes thinner and the particles approach each other, which gives the general shrinkage or contraction of the body.

When these particles come into contact there can be no further shrinkage although there is still a considerable percentage of moisture in the mass. During this second stage when the particles are coming into contact the volume of moisture is decreasing at a greater rate than the shrinkage. It is probable that if all the particles were of exactly the same dimensions there would be a very definite cessation of shrinkage when the particles come into contact. Due to the fact that the particles vary greatly in dimensions and the surface dries faster than internal points, there is a gradual falling off of the shrinkage, while the moisture continues to decrease at about the same rate.

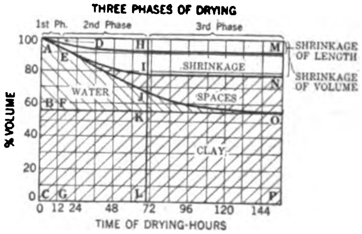


Fig. 15

Bourry's diagram of the relation of drying to volume, showing the percentage of clay, water, spaces, shrinkage of volume, and shrinkage of length.

In the third stage the particles have all reached their minimum separation and the shrinkage entirely stops. During this third stage, however, moisture is still given off until finally all the free moisture has disappeared and there remains only the moisture of constitution in the particles themselves.

Bourry illustrates these three phases (Fig. 15) by tests on a cylinder of clay having a length of five times the diameter. The diameter was 1.575 in. (4 cm.) and the length 7.874 in. (20 cm.). The volume of solid material in the beginning was 55 per cent and the volume of water 45 per cent. At the end of the first period, when the shrinkage and water decreased together, there was a reduction of 5 per cent in the volume which came from the loss of 5 per cent of the water, leaving 40 per cent. At this time the spaces between the particles were *O*; the lineal shrinkage was 3.7 per cent or 0.74 cm.

At the end of the second stage of drying the volume of the clay was still 55 per cent, the volume of the clay and water was 67 per cent, and the volume of the water 12 per cent. The volume of the spaces between the particles was now 11 per cent. The total shrinkage was 22 per cent. The lineal shrinkage was 8 per cent.

At the end of the third period the percentage volume of water was 0. The percentage volume of the spaces between the particles had increased to 23 per cent but the total shrinkage remained as at the end of the second period, namely 22 per cent. Also the percentage lineal shrinkage remained 8 per cent. All of these relations are better shown in the accompanying table, taken from Bourry's curves which are reproduced in Fig. 15.

At the end of periods	1st	2nd	3rd
Per cent volume of clay	55.	55.	55.
“ “ “ “ “ and water	95.	67.	67
“ “ “ “ water	40.	12.	0
“ “ “ “ spaces between particles	0	11.	23
“ “ “ “ shrinkage	5	22.	22.
Per cent shrinkage in length	3.7	8.	8.
cm. “ “ “	0.74	1.6 cm	
“ “ average per hour	0.06	0.027	
mils “ “ “ “	24 mils		
“ “ “ “ minute	0.4 “		

It is interesting to note that the lineal shrinkage decreased at the rate of 24 mils an hour or at the rate of 0.4 mil per minute. If we are to consider some scientific instrument for measuring the rate of shrinkage here is a variable factor which is available for use.

Another factor for use would be the variation in weight. For the sake of completeness Bourry's tabulated data of this test is given below.

Duration		Weight of				Volume of				
			Water				Water			
Days	Hr.	Clay per cent	per cent	Per cent change	Shrinkage lineal Per cent	Clay per cent	Per cent	Per cent change	Spaces per cent	Per cent total volume
	2	75	25.0		2.1	55.1	44.9			100.0
	12	75	21.5	3.5	3.7	55.1	38.7	6.2	0.0	93.8
1	24	75	18.0	3.5	5.1	55.1	32.4	6.3	1.8	89.3
	36	75	14.5	3.5	6.5	55.1	26.1	6.3	3.3	84.5
2	48	75	11.2	3.3	7.6	55.1	20.2	5.9	6.4	81.7
	60	75	8.0	3.2	8.0	55.1	14.4	5.8	9.4	78.9
3	72	75	5.6	2.4	8.0	55.1	10.1	4.3	12.7	77.9
	84	75	3.8	1.8	8.0	55.1	6.8	3.3	16.0	77.9
4	96	75	2.5	1.3	8.0	55.1	4.5	2.3	18.3	77.9
	108	75	1.7	0.8	8.0	55.1	3.1	1.4	19.7	77.9
5	120	75	1.1	0.6	8.0	55.1	2.0	1.1	20.8	77.9
	132	75	0.7	0.4	8.0	55.1	1.3	0.7	21.5	77.9
6	144	75	0.3	0.4	8.0	55.1	0.5	0.8	22.3	77.9
	156	75	0.0	0.3	8.0	55.1	0.0	0.5	22.8	77.9

As an additional factor the rate of drying has considerable to do with the value of the shrinkage. Two identical samples were dried at different rates. One sample was dried in one day and shrank 7.75 per cent. The other sample was dried slowly in 15 days and shrank 8.50 per cent, which is an increase of 10 per cent in the shrinkage.

The rate of drying is affected by the consistency, that is to say, by the percentage of moisture present. Bourry gives an illustration of samples of plastic porcelain in which the initial quantity of water was 10 per cent, 20 per cent and 30 per cent. The one with the highest percentage of water dried the fastest. The results are shown in the following table:

Proportion of water	10 Per cent	20 Per cent	30 Per cent
Loss in per cent in 1 day	4%	5%	8%
Days to dry	4-1/2	5-1/2	6-1/2
Ratio of days to dry	1	1.22	1.44

Since the rate of evaporation is affected by the amount of moisture present, if a tool used in forming the plastic porcelain squeezes out moisture locally mechanical strains will be introduced during drying which may cause laminations or cracks. This result may be due to the difference in content of moisture or it also may be due to a segregation of the plastic clay from the non-plastic powdered flint. The plastic clay will ooze through the solid flint and may produce locally a non-homogeneous condition. This non-homogeneous condition will affect not only the rate of drying and the plasticity but also the vitrification in the furnace when it is at its maximum temperature.

Bourry gives very little definite information regarding the content of moisture in the plaster of Paris molds. When the plaster of Paris molds are very dry the moisture is taken away from the surface of the porcelain, in contact with the mold so rapidly as to cause it to check. Where the " blank" is subsequently turned down on a lathe these surface cracks are turned off.

In every case it must be understood that moisture cannot flow unless there is a different degree of moisture. Consequently the surface of the porcelain must always be drier than the interior and the problem is to keep this difference in degree of moisture to a value which will not cause cracks from unequal shrinkage. The movement of moisture from particle to particle corresponds to the transference of heat through an ordinary solid body, also to difference of potential in the electrical circuit. If projecting parts are used on the porcelain surface it is sometimes necessary to retard the evaporation from these localities where the area exposed, relative to the volume, is much greater than the same ratio for the main body of the drying porcelain.

39. Flaws Developed During the Process of Drying and Dehydration in the Kiln

Another critical stage apparently, in the manufacture of porcelain, occurs in the kiln at a temperature of 400 to 500 deg. cent. At this temperature the water of composition of the clay is thrown off. The changes taking place in the green porcelain are illustrated by a study made by Messrs. G. H. Brown and E. T. Montgomery in the U. S. Bureau of Standards, published in Bulletin No. 21. Fig. 16, taken from the Bulletin, is the rectangular diagram of the loss of weight in per cent for different temperatures of firing on a North Carolina kaolin. The material was air-dried to 110 deg. before this test was started, so that probably the free moisture had been all evaporated. From a temperature of 110 to 400 deg. the loss in weight was slightly less than two per cent but between 400 and 450 deg. the loss of weight was approximately 10 per cent and the total loss of weight up to 800 deg. was 14 per cent. From 800 to 1000 deg. no further decrease in weight took place. When we consider that the air-drying stage of a porcelain piece will usually require about three weeks and the decrease in moisture is less than occurs in the porcelain kiln it is seen that a possible damage might be done to the porcelain material during the early and apparently unimportant part of the firing. To remove from the body of a piece of porcelain 10 per cent of its weight in the form of moisture within a few hours would necessarily involve a rapid movement of moisture from particle to particle. The green porcelain is in a stage of drying in which the rate of drying may be high since there are only mall changes in volume

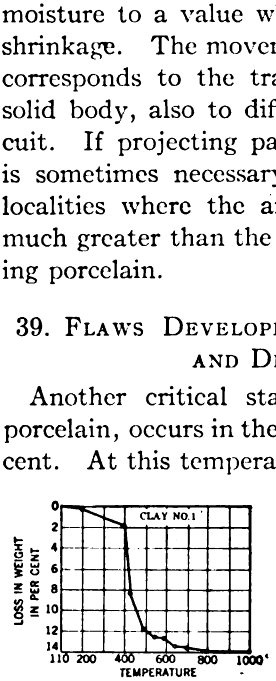


Fig. 16
The relation of loss of weight for different temperatures of firing on kaolin. (Messrs. G. H. Brown and E. T. Montgomery, Bulletin No. 21. By courtesy of Bureau of Standards.)

taking place. The spaces between particles increase somewhat, that is to say, the porosity is greater at this stage. It is possible that a considerable expansion of the material may take place during this period and if the rise in temperature is too rapid the material will be puffed and warped by the sudden changes. If the air-dried porcelain is placed directly into a hot electric furnace it will be reduced to a powder.

There is a limit to the thickness of porcelain that can be successfully fired (in general about 1.5 in.) and it may be that one of the factors which gives this limitation is the method of firing universally employed, especially the rate of change of temperature in the neighborhood of 400 deg.

The effect of time on this dehydration of the kaolin is given in Fig. 17, taken from Bulletin 21. This curve shows that at a temperature of 450 deg., the most of the moisture will be thrown out in about 30 hours. At 500 deg. most of the moisture will be thrown out in five hours.

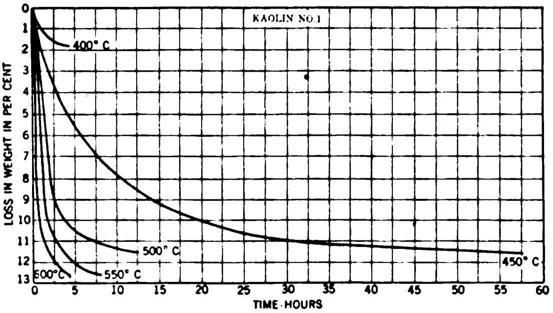


FIG. 17

The effect of duration of time on the dehydration of kaolin. (Bulletin No. 21. By courtesy of Bureau of Standards.)

40. VITRIFICATION

Another important stage of the formation of porcelain is the time of maximum temperature. The chemical dissolutions and combinations which take place in the semi-molten condition require considerably more time than when the materials are in a molten fluid condition. Consequently a temperature of 1310 deg. held for several hours may give complete vitrification, whereas a shorter time would leave the material under-vitrified. Briefly stated, the vitrification depends not only on the temperature but also on the duration of the high temperatures. The time of cooling is usually so slow that in general this is a stage of comparatively little danger, since the porcelain has already attained the characteristic of having a very small coefficient of expansion.

41. SUMMARY OF THE IMPORTANT POINTS IN THE MANUFACTURE OF PORCELAIN FOR ELECTRICAL PURPOSES

1. Composition (chemical and molecular).
2. Keeping the ingredients uniformly mixed.
3. Keeping the ingredients uniformly plastic.
4. Keeping the mass from unequal contractions in drying.
5. Keeping the mass from unequal contractions in firing.
6. Bringing the firing temperature to the proper range and holding it for the corresponding proper period of time to fill up the pores with vitrifying flux but not to cause a high degree of vitrification, forming a brittle, fragile mass.

PART III. EXPERIENCES AND EXPERIMENTS IN TESTING PORCELAIN WITH THE HIGH FREQUENCY OSCILLATOR

42. ON THE SUBJECT OF THE DETECTION AND MEASUREMENT OF SUPERPOSED HIGH VOLTAGE ON THE WAVE TRAINS OF THE OSCILLATOR, THE SUPERPOSED VOLTAGES BEING DUE TO THE REFLECTION OF THE LOCAL OSCILLATIONS OF CREEPAGE SPARKS

It was noted in two different sets of tests that a type of porcelain bushing having an average puncture potential of 85 kv. under oil may *apparently* haye a higher value of puncture voltage, as represented by the setting of the sphere gap, when a creepage spark is allowed to play over the surface of the oil between the two electrodes, the porcelain bushing in this case being near the surface of the oil so that its central metallic conductor is parallel to the oil surface and therefore in a position to encourage the formation of a creepage spark. Under these conditions of creepage spark the average puncture potential of a bushing of the same type was over 100 kv., an increase of 17 per cent.

There are so many variable factors in comparing these two conditions that it is difficult to draw directly definite conclusions as to the cause of the difference.

The following is a description of the two sets of tests, after which a discussion will be given of the various factors involved.

A porcelain bushing, 13.5 in. long, and having an average thickness of 0.94 in. at the thinnest part of the corrugation, was supported horizontally on a metal rod and immersed in oil, Fig. 18. The metal rod was connected to the ground and a vertical electrode was placed in the groove of the corrugation. The width of the metal electrode was about one inch and its thickness about 3/16 in. with the edges rounded off. Both these electrodes projected out of the oil at an average distance of 12 in. apart. Consequently, when the potential was applied above a certain voltage, sparks over the surface of the oil were produced between the two electrodes. The question arises, did the creepage sparks increase the gap setting of the spheres by superposing surges on the wave trains of the oscillator? We know from much experience in testing with 60-cycle fre-

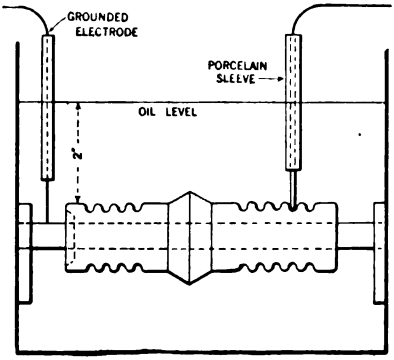


Fig. 18

One method of applying high-frequency potential to porcelain bushings under oil. The end of the electrode on the right was two in. wide and ⅛ in. thick, rounded on the edges.

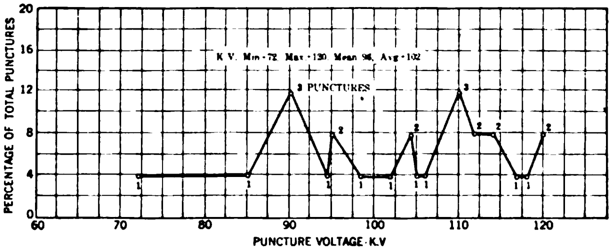


Fig. 19

Puncture voltage of porcelain bushing under oil. Representation of the percentage of punctures which took place at different impressed voltages as the voltage was gradually raised at the rate of about 5 kv. every 10 seconds. The numbers at the points represent the numbers of punctures at different spots of the same bushing.

quency that local sparks on an insulator or lightning arrester under test, will greatly increase the equivalent gap in parallel, although the voltage by ratio remains the same with or without the sparks.

There were 13 puncture tests made on one end of the bushing and 12 on the other, making a total of 25 punctures. The values of puncture potential, minimum, maximum, mean between the extremes, and average, are given in the table farther on.

It should be understood that these figures are not actual voltages but the voltages corresponding to the gap setting of the sphere gap as calibrated by tests with 60 cycles. The data of the tests are plotted in Fig. 19.

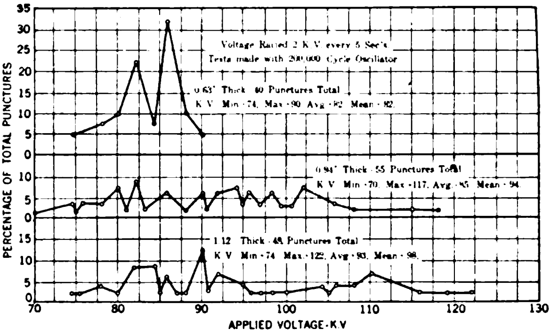


FIG. 20

Puncture of porcelain bushings under oil. Three different thicknesses are shown. Percentages of total punctures are plotted in relation to the kilovolts at puncture. Each curve represents punctures at different points on the same piece of porcelain.

Another piece of porcelain of the same type, thickness, and manufacture was tested under identical conditions except that the creepage spark over the surface of the oil was entirely prevented. The plot of the data is shown in Fig. 20 of the second curve. There were 55 punctures total with an average puncture potential of 85 kv. as compared to 102 kv. in the previous test. This information is tabulated in the table below.

	One bushing tests allowing creepage spark			Another bushing tests with no creepage spark
	1st end	2nd end	Total	
No. of tests	13	12	25	55
Minimum	72	90	72	70
Maximum	114	120	120	118
Mean	93	105	96	94
Average	96	107	102	85

To forestall questions which are bound to arise the following speculations are given: So far as the data here collected are concerned, the cause of this difference may be any one of several, alone or in combination. These possible causes will be enumerated: First, the porcelain bushings were fired at different times, and possibly at different temperatures, and the porcelain material may not have been identical in dielectric strength. (As a matter of fact tests will be given later to prove that the difference in porcelain constituted the entire difference in dielectric strength.)

Second. The creepage sparks over the oil make a demand for more energy from the oscillator and in so doing the regulation drops the voltage and therefore may require an increased length of the control gap.

Third. Momentarily there may be impressed on the circuit a high voltage corresponding to the unloaded condition of the transformer. This voltage may start a new creepage spark.

Fourth. The rapid extinction of the creepage sparks may reflect local oscillations of extremely high frequency back to the sphere gap and these local oscillations may cause the sphere gap, at a certain setting, to spark over more easily due either to a higher voltage or to a higher frequency,—or both may exist at the same time.

Fifth. Again, another factor is involved in the relative dielectric spark lag of the 0.94 in. thickness of porcelain, and the long creepage spark over the surface of the oil. If the creepage spark takes place more quickly than the puncture of the porcelain the creepage spark by absorbing more energy and dropping the voltage may be an actual protective gap to the porcelain.

Sixth. There is also a factor which enters into this problem in the matter of time of application of voltage on the surface of the porcelain. The electrode employed has comparatively thin edges and therefore its potential gradient will be high at the surface of the porcelain. This high potential gradient when the voltage is carried up to a value approaching the puncture potential, will begin to damage the porcelain locally at the electrode. Failure of the porcelain should therefore be a gradual growth depending upon the time of application.

If the user of the oscillator had to take into account all these complex factors it would require a rare technical skill. It will be the object of the studies which immediately and later follow, to show that complications of superposed oscillations, frequency, and so forth are usually negligible factors in testing insulators with the oscillator. The problem is thereby stripped of most of its complications, leaving a simple condition which takes care of itself automatically in the practical procedure of testing.

43. TESTS TO DETERMINE WHETHER CORONA STREAMERS AND CORONA SPARKS PRODUCE LOCAL OSCILLATIONS IN THE CIRCUIT WHICH AFFECT THE SPHERE GAP SETTING

In the previous tests of porcelain bushings the electrodes were so arranged that a spark could take place over the surface of the oil just above the bushing. With this arrangement it was possible to limit the stresses on the bushing to a local point where the upper electrode touched it, yet at the same time get a creepage spark over the surface of the oil. Ordinarily when tested in air the creepage spark over the surface of the porcelain is liable to find some weaker spot than the one where the electrode rests and thereby cause a discontinuation of the experiments by puncture.

In order to exaggerate the effects of creepage sparks, a pane of glass $\frac{1}{8}$ in. thick was used as dielectric. The electrodes consist of two iron rods $\frac{1}{2}$ in. in diameter with rounded ends. These electrodes were placed in the same axial line on opposite sides of the glass.

44. FIRST SET OF TESTS ON GLASS

In the first set of tests the control gap and equivalent spark gap were increased at the same time. As the impressed voltage was increased the corona streamers, mostly blue but sometimes slightly white, increased in area over the surface of the glass. At the maximum voltage obtainable, namely 45 kv. by spark gap with a setting of 11.1 kv. on the control gap, the radius of the corona was $5\frac{3}{4}$ in., giving a total area on each side of the glass plate of 104 square inches. The following series of readings was taken:

Control Gap	Spark Gap
1.8 kv	32 kv.
3.0 "	34 "
4.6 "	36 "
6.7 "	38 "
11.0 "	40 "

As an explanation of why the voltage generated by the oscillator is apparently so very limited we must look to two different causes. First, the corona is equivalent to an increase in capacitance. Second, the corona absorbs energy. Either of these causes will limit the potential of the oscillator by over-loading it.

In order to determine the effect of capacitance, tinfoil plates, 7 by 9 in., (63 sq. in.) were used as electrodes. As a result the maximum voltage obtained was reduced from 45 kv. as given in the previous test, to 28 kv. Even at 28 kv. there was a corona of 1½ in. visible in daylight surrounding the tinfoil plates. This made a total area covered by plate and corona of 10 by 12 in. (120 sq. in.). During this test the control gap was set on 11.5 kv. With the electrodes alone the area was 104 sq. in. which was increased to 120 sq. in. with the plate and corona together. This increase of 16 per cent in area reduced the voltage by 37 per cent. The area of corona around the metal plates was 57 sq. in. which is a little less than half of the corona area in the previous case. It would appear from these figures that the capacitance was a large factor in reducing the voltage at the terminals of the oscillation transformer.

Capacitance of glass plate ⅛ in. (0.322 cm.) thick and an area of 104 sq. in. (670 sq. cm.) is 1.1 milli-microfarads (10^{-9} farads).

At 300,000 cycles and 45 kv. this capacitance of 1.1×10^{-9} farad gives a momentary load of about 29 amperes or 1170 kv-a.

This capacitance of 1.1 milli-microfarads is equivalent to the capacitance of thirty suspension type insulators in parallel, which is three to six times full load for this oscillator.

45. Equivalent Spark Gap of Corona on a Glass Plate

The equivalent spark gap of corona on glass plates is dependent upon the voltage applied. Two tests of a slightly different nature follow. In the first one, the spark gap was set permanently on 37 kv. and the control gap was gradually increased. With the control-gap setting of 3.2, a spark was formed around the edge of the plate which was 4½ in. away from the electrode, making a total length of spark of 9 in. No discharges took place over the spark gap for this low setting of the control gap.

At a setting of 4 kv. of the control gap there was one discharge over the spark gap in seven total.

At five kv. setting of the control gap there were four sparks over the spark gap to ten total.

At six kv. setting of the control gap there was about equality between the spark gap and the spark around the glass plate, that is to say, five out of ten total.

At seven kv. setting of the control gap the sparks over the spark gap increased to seven in ten impulses.

At eight kv. setting the sparks over the spark gap increased to eight in ten impulses.

At 8.5 kv. setting of the control gap there were nine discharges over the spark gap out of a total of ten impulses.

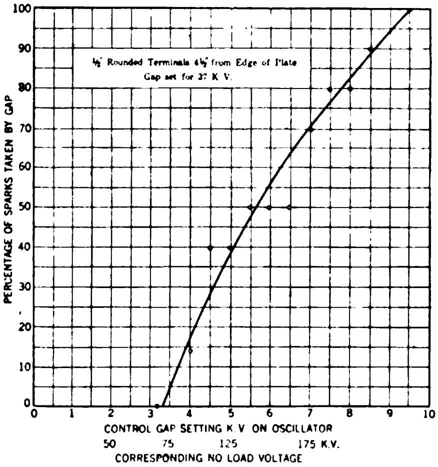


FIG. 21

Arc-over tests on a glass plate ⅛ in. thick and with the electrodes 4½ in. from the edge of the plate. Electrodes were placed in the same axial line perpendicular to the plate, consisting of ½ in. rods with the ends rounded. The gap was set constantly on 37 kv. and the control gap was gradually increased. For low values of the control gap 3.2 kv. all the discharges took place over the surface of the glass and a creepage spark of total length of 9 in.

At nine kv. setting of the control gap there were 19 discharges over the spark gap out of 20 total.

At 9.5 kv. setting of the control gap there were 40 discharges of the spark gap out of a total of 40, but at a setting of ten kv. on the control gap one discharge took place over the glass plate, making a record of 39 over the spark gap to 40 total.

At a control gap setting of 10.5 kv. there were 100 successive discharges over the spark gap out of a total of 100 impulses, there being very slight tendency to spark on the glass plates.

In this set of tests it is seen that the equivalent spark gap of electrodes separated by a thin glass plate depends upon the value of the applied potential the same as has been shown in tests on lightning arresters using Leyden jars charged from the static machine.

The change in the equivalent spark gap is shown diagrammatically in Fig. 21.

46. THE EQUIVALENT SPARK GAP WITH THE CONTROL GAP REMAINING CONSTANT

In the next set of tests the control gap was set on 3.5 kv. which was just sufficient to cause 4½ in. radius of corona, and a spark around the edge of the glass plate. It was necessary to reduce the spark gap from 37 kv. setting to 32 kv. setting in order to take the spark away from the glass plate. It should be recalled that at high control-gap setting the spark gap set even on 37 kv. took all the discharge away from the glass plates.

By increasing the control gap setting to four kv. and with a setting of 32 kv. on the spark gap, it was possible to take away the discharge from the glass plates and keep it in the spark gap. When the spark gap was increased two kv. to 34 kv. there were 32 discharges over the spark gap out of a total of 40, leaving eight discharges over the glass plate.

With the control gap setting of 10.5 kv. it was necessary to elongate the spark gap to 44 kv. before the discharges would all take place over the glass plate.

In none of these tests do we find the solution of the problem of the effect of the oscillation set up by the corona streamers and corona sparks. Therefore the next set of tests is planned to throw some light on this subject.

47. THE PUNCTURE VOLTAGE OF A GLASS PLATE WITH A DROP OF OIL AROUND THE ELECTRODES

The same electrodes were used and a glass plate lying horizontally had a few drops of oil placed around the upper electrode. The main gap of the oscillator was then closed momentarily a number of times with control gaps ranging from one kv. up to 2.5 kv. The spark gap voltages corresponding were from 32 kv. up to 40 kv. After the eighth brief application of potential with a setting of 2.5 kv. on the control gap and 40 kv. on the spark gap the glass was punctured. This experience gives a very definite clue to the immunity of puncture in the previous test. It should be recalled that the control gap setting was increased to 11.1 kv. and the spark gap to 45 kv. without causing a puncture of the glass. We now applied less voltage and very quickly got a puncture. The distance of the electrode from the edge of the glass in this last case was only 1.3 in. and occasionally there would be sparks break through or over the surface film of oil and spark around this short width of glass.

The obvious explanation of this phenomenon of puncture of glass at lower voltage than it had previously withstood is in the difference in concentration of the electrostatic field. Without the film of oil the voltage gradient at the electrode can rise only to a value which will start the corona discharge in air and any further increase in the voltage simply increases the area covered by the corona which, in effect, increases the area of the plate and gives a better distribution of the electric field over the plate. On the other hand, when the oil is used, the corona streamers are to a very great extent restricted and the potential is concentrated locally and causes a disruptive spark to puncture the glass.

While the variations in the equivalent spark gap involved a complicated study of dielectric spark lags the actual use of the oscillator to measure these different conditions is very simple. We must assume in each case that even if the spark gap does not measure the actual voltage it does measure always the tendency to spark which is the condition in the circuit against which it is desirable to protect. In testing porcelain bushings in air the same effect will take place as shown in the tests on glass in that the corona at the edges of the electrodes will decrease the effect of the sharp edges of the electrodes. In testing thin pieces of porcelain in air many new points of the porcelain are reached by the spreading of the corona streamers and there will be added the additional factor of puncture through local weaknesses in the porcelain. The porcelain is not nearly as homogeneous as glass. The wave trains generated are of very high frequency and the superimposed oscillations from local sparks, while higher in frequency, are, comparatively speaking, not much higher. As a result the spark gap is not affected very much. In other words, the change of frequency and wave front from 60-cycles to say a million cycles is enormous as compared to the change of frequency and wave front from the oscillator to that of the local oscillations. The first ratio is of the order of 17,000 and the second of the the order of 3. Herein lies the simplicity of testing with the oscillator.

In testing porcelain under oil one must take into account the maximum voltage gradient which can be applied at the contact point between the electrode and surface of the porcelain without damaging the porcelain. This value of voltage gradient is readily determined experimentally for any particular shape of electrode that it is desired to use. Such tests will be given further on.

48. FURTHER STUDIES OF PUNCTURE POTENTIAL OF PORCELAIN UNDER OIL BY THE USE OF THE OSCILLATOR

Three thicknesses, namely 0.63 in., 0.94 in., and 1.12 in., were tested and recorded. The test pieces were corrugated porcelain bushings of the general form shown in Fig. 18. In Fig. 20 three curves are shown of tests on the three thicknesses. The three pieces of porcelain were each punctured a number of times. By conducting many tests on one piece of porcelain it is thus possible to keep the factor of quality of the porcelain constant. The three curves are entirely independent. The method of test was to gradually raise the potential two kv. every five seconds until puncture occurred. In plotting this data the kilovolts at puncture are taken as the abcissas and the percentage of the total number of punctures at the different voltages as the ordinates. The upper curve is the result of 40 punctures total, all on one test piece. The minimum puncture potential was 74 kv. There were two punctures at this voltage, which is 5 per cent of 40 total punctures. Percentage is used instead of the actual number of punctures in these curves so that comparisons can be made between the three different thicknesses tested. There were only two places tested that withstood 90 kv., the maximum value. This is also shown as 5 per cent on the upper curve. Attention is directed to the peculiar low point at 84 kv., as it will be shown in a different way in another diagram later. It may or may not have any special significance. Attention should also be directed to the small range of puncture potential for this thickness of 0.63 in. Most of the punctures occurred between 80 and 88 kv. These general relations may be interpreted from a tabulation of the maximum, minimum, average, and mean between the extreme values as printed on the curves. The ratio of the minimum to the maximum is 82 per cent and the mean and average values are identical, showing general symmetry in the results.

The second curve (0.94 in. thick) is the result of a total of 55 punctures taken on one bushing. This greater thickness shows a wide range of puncture voltage. The minimum puncture voltage of 70 kv. was even less than the thinner test piece. The maximum puncture voltage was 118 kv. but there was only one spot that withstood this potential. For this greater thickness of porcelain there is no definite puncture voltage as in the previous case. The ratio of the minimum to the maximum is 60 per cent which is 22 per cent below the range of the thinner porcelain-just-given above.

In the third curve the thickness was 1.12 in., and a total of 48 punctures was made on the porcelain piece. Here again the puncture voltage is spread over a wide range with no definite point of failure. Apparently in both of these thicker pieces the conditions of manufacture or test of the porcelain were such as to give a wide range of dielectric strength. The ratio of the minimum spark potential in this case was also 60 per cent. In the early part of the work it was endeavored to get as many punctures as possible on one sample. In so doing it was found that the cracks from one puncture would occasionally carry into the spot where the successive test potential was applied and this spot would thereby be weakened. As soon as this fact was established greater distances were made between puncture points. To further insure that the cracks did not carry from one puncture hole to the next, further precautions were taken. The punctures were filled with red stain and then thoroughly dried, the porcelains were then broken into pieces and where the red stain showed that a crack had carried from one punctured point to another the second reading was thrown out.

49. A Replot of the Data of Fig. 20 to Show Tentatively Possible Natural Gradations of Flaws

In Fig. 20 the percentage of the total number of punctures at each value of kilovoltage applied was given. In Fig. 22 the values of punctures are summed up from the lowest voltage to the highest voltage. Both curves, 1 and 2, show a peculiar shoulder at 82 kv. All the curves show a bend at the highest values. Tentatively, we may interpret these curves as follows: It is conceivable that there is a certain class of flaws which are devloped between 70 kv. and 82 kv. Above this value we get into the condition of the normal strength of the porcelain which requires a considerable increase above 82 kv. before the number of failures again increases rapidly. In the case of curve 1 it required 85 kv. to increase the percentage suddenly from 53 to 85. In curve 2 the range was wider, being between 90 kv. and 100 kv. In the third grade of the dielectric strength given by the porcelain there are those local spots which approach perfection in the homogeneity of the porcelain material. Therefore the high-voltage strains which are at the limit of dielectric strength do not develop into a puncture so easily. As already stated, this analysis is only tentative, and even if it is true for this particular grade of porcelain it may not apply in the same way to a different mixture of material. We have found, however, that there have been in nearly every case fairly definite degrees of flaws which can be developed in rather definite ranges of potential. To illustrate this idea, the grades might be divided as follows: First, accidental cracks or lamination which are at more or less of an angle to the surface of the porcelain and which therefore decrease the puncture length through the porcelain. In the second grade would be those flaws of the nature of "blebs" or closed bubbles also open pores. In the third grade there exists the highest degree of homogeneity with very slight differences in dielectric strength from particle to particle as we pass from surface to surface.

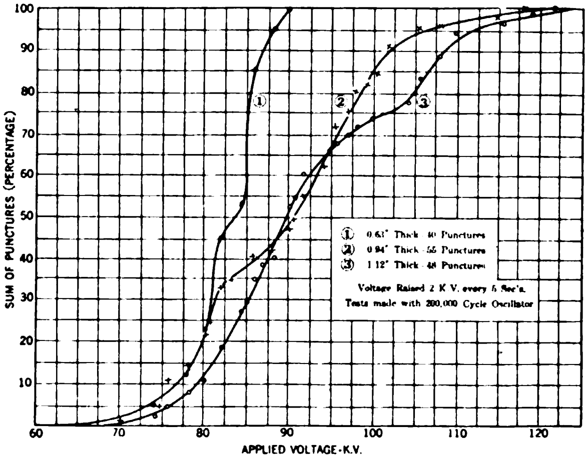


FIG. 22

A replot of the puncture tests of Fig. 20. The kilovolts of puncture versus the sum of punctures. The shoulders on the curves may represent a different grade or kind of flaw in the porcelain.

50. TESTS WITH THE ELECTRODE PLACED SUCCESSIVELY IN THE VALLEY OF EVERY ADJACENT CORRUGATION IN THE SURFACE OF THE BUSHING. THE RESULTS SHOW THE INTERNAL MECHANICAL STRAINS DUE TO SHRINKAGE

In the records of the tests shown in Fig. 19 the upper electrode was always moved a distance of two corrugations away from the previous test. In the earlier tests the electrode was moved into the adjacent corrugation. In so doing some interesting conditions relative to internal strains were disclosed. Fig. 23 shows one of several punctures which took place in the porcelain. It will be noted that there are two streaks which are only 0.25 in. apart but are 0.81 in. long. If the porcelain had been uniform there would have been a straight puncture through the porcelain perpendicular to the surface (0.62 in.). The fact that there are two punctures about 0.8 in. long side by side following parallel paths separated by only one-quarter inch indicates that there were mechanical strains in the porcelain, placed there during the manufacture, which caused more or less of a cleavage or a line of weakness. This porcelain was jiggered into the form of a long, smooth tube while it was in a plastic condition. After partial drying sufficient to give it enough tenacity to hold together, it was placed on a lathe and the grooves or corrugations turned into the surface of the "blank." The material was then allowed to complete its drying. Probably during this second process of drying these laminal strains were introduced. There is every reason to believe that the

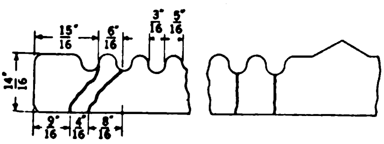


FIG. 23

Parallel puncture streaks close together as compared to the length of the streak. This phenomenon shows latent weakness in the porcelain at the end of the bushing, which seems to be due to the process of air drying.

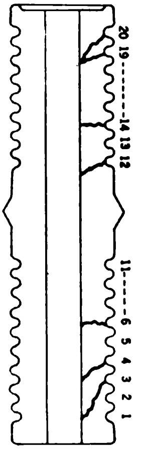


FIG. 24

A number of puncture streaks are shown at different lengths of the bushing similar to those of Fig. 23. It should be noted that all the puncture streaks at the ends and at the middle are in a downward direction, which seems to indicate the effects of air drying in causing latent cleavage surfaces in the porcelain.

lamination is not due to a layer of flint, because in the working of the soft clay there is no opportunity to systematically cause layers in the direction shown by the direction of the punctures.

In Fig. 24 are shown the paths of puncture of another porcelain bushing at several points along its length which would tend still further to confirm the belief that the cracks were due to air-drying rather than to lack of homogeneity of mixture or shrinkage in firing. The lines drawn from the grooves to the inside surface of the porcelain bushing show that at the ends and at the middle the direction of the puncture is at an angle from the radial direction and all in a parallel direction. Punctures at other points than at the ends or the middle are radial punctures. The possible explanation is as follows: This porcelain bushing was stood on one end to dry. It was therefore restricted in its radiation of moisture from the surface at the base and was given extra freedom of evaporation at the upper part where the central hole was open to a slight movement of the air in the neighborhood. About half-way along the bushing the thickness was increased to be used as a support and at this point also there would be a difference in drying at different depths. The under side of this shoulder would naturally get more evaporation than the upper side. Since the thickness was greater a greater amount of moisture had to be extracted, requiring a longer time for different depths. If these angular weak spots had been produced by a variation in the mixture they would have been more or less uniform in the bushing from end to end. If the angular weaknesses were due to firing in the kiln there would seem to be no reason for the peculiar distribution at the top and bottom, although naturally the thicker part of the bushing at the midway point would come in for inequalities of contraction. As a matter of observation, two small surface cracks were noted on the inside of the bushing at the thickest point but these cracks did not show sufficient weakness to divert the puncture discharge from its path, which, by the way, ended about $\frac{1}{4}$ in. from the surface crack.

51. FAULTS IN THE SKIRTS OF SUSPENSION INSULATORS

When the upper side of a skirt of an insulator is covered by tinfoil and the insulator inverted in a bath of oil, localized potentials can be applied by means of a small electrode resting in one of the corrugations or valleys between adjacent petticoats. In a number of test samples a very uniform homogeneous porcelain material was found. This was indicated by punctures directly between electrodes from surface to surface of the porcelain. Occasionally, however, conditions of internal mechanical strains were revealed by the fact that the puncture took place at an angle to a perpendicular line between surfaces and sometimes traversed a distance nearly twice as great as the thickness of the porcelain. The direction of the puncture was indicated subsequently when the porcelain was broken up with a hammer or by squeezing it in a vise. Fig. 25 shows a sketch of two different types of punctures that were found.

In a number of punctures which occurred in the head of pin-type insulators a careful examination was made by staining and breaking up the porcelain by hammer blows. A characteristic puncture streak is shown in Fig. 26. These samples were shown to a porcelain manufacturer who immediately set the cause of the trouble to an improper use of the tool used in forming the thread on the inner surface of the porcelain. With the information already given, one may attribute the fault to insufficient plasticity, which may have been due to lack of water, lack of enough ball clay, or too large particles of flint. It is easy to conceive of the more plastic clay being squeezed out from under the tool, leaving the material directly under the tool of a different consistency from the rest of the body of the porcelain. From this difference in body, weaknesses may be caused, either in the rate of drying or in the vitrification due to the improper proportioning of the ingredients in this locality. In one case there was a perceptible surface crack in the porcelain which was the beginning of a puncture streak. In this case one may tentatively infer that the damage was initially done in drying and might have been found by the application of oil to the green porcelain.

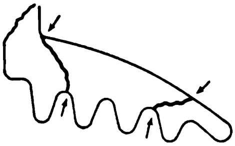


FIG. 25

Directions of puncture in a skirt of a porcelain insulator where the discharge takes a path much longer than the shortest distance between surfaces. This indicates a weakness in dielectric strength due to shrinkage strains.

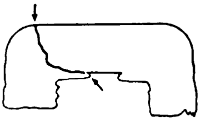


FIG. 26

Direction of puncture in the head of a pin-type insulator, showing a line of weakness due primarily probably to an improper manipulation of a forming tool, while the porcelain was in a plastic condition. All paths of puncture which do not take the shortest distance indicate a line of weakness in the porcelain.

In general one may conclude that porcelain which does not puncture through the shortest distance is non-homogeneous.

52. The Growth of Corona on Insulators

The growth of corona around the electrodes and on different parts of the insulators has been successfully used as a basis of design. The oscillator with its high frequency is well adapted to bring out the characteristics of design by this method. Some tests are given in the following table to illustrate the characteristics as disclosed by the oscillator. The tests were invariably made in the dark to be able to note the first visible formation of corona.

Suspension type insulator No. 1	Kv.	Per cent of spark-over
Spark-over voltage	86	100%
Brush discharge from pins	33	38%
" " around 1st inner petticoat	47	55%
" " at cap	47	55%
" " around 2nd petticoat	74	86%

It was found impossible to brush discharge over the third petticoat without a spark-over on the insulator.

Suspension type insulator No. 2	Kv.	Per cent of spark-over
Spark-over voltage	82	100%
Brush discharge at pin	42	51%
" " over inner petticoat	48	59%
" " 2nd petticoat	59	72%
" " 0.75 in. long around cap	59	72%
" " over 3rd petticoat	72	88%
" " " 4th "	74	90%

In studying the growth of corona on the pin-type insulators, eight different samples were used. In the points of Fig. 27 the appearance of the corona in per cent of the spark-over voltage is plotted as ordinates and the kilovolts of spark-over voltage as abcissas, the points corresponding to the initial formation of corona which invariably took place around the pin. A considerable variation in the distribution of potential is evident from the wide variation between the limiting curves as shown in Fig. 25. The variation is from 30 per cent for the high-voltage insulators, to 76 per cent for one of the best conditions of the lower-voltage insulators. Naturally the higher the spark-over voltage of the insulator the lower the percentage, because the corona depends upon the potential gradient. The potential gradient which produces corona on the pin does not differ very widely for the different types of pins and insulators.

SIGNIFICANCE OF THESE TESTS

The significance which may be drawn from tests of corona are too complex to be considered in a paragraph. They are valuable to the designer but several points of design must be taken into account in each particular insulator. From some points of view the ideal design of an insulator would be one producing no corona until the arc-over voltage of the insulator was reached. From a practical point of view the laboratory test, unless made under the same conditions as found in the operation of the insulator, does not necessarily give the best design. For example, if an insulator is to be designed for a very dusty country or where soot and smoke will be deposited on the surface of the porcelain the conditions call for extra long surfaces for creepage. If such an insulator in a clean condition is tested in the laboratory for the appearance of corona, the corona will appear at a comparatively small fraction of the arc-over voltage. Yet if this insulator is thoroughly coated with a semi-conductor, as would occur in practise, it is quite probable that the apparently faulty design would be far better than one with shorter skirts which in the laboratory test in a clean condition gives a higher percentage of voltage for the appearance of corona. In brief, one must take into account the use of the insulator and reproduce the operating conditions, as far as possible.

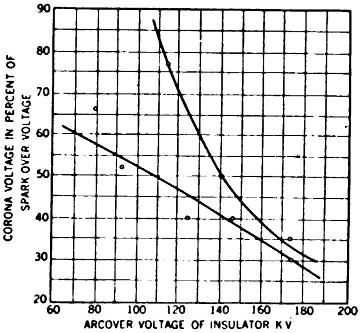


FIG. 27

The first appearance of corona on pin-type insulators using the oscillator as a source of power. Arc-over voltage of the insulator versus the percentage of arc-over voltage at which the first corona appears on the pin. The two curves show the wide range of variation which can be found in insulators on the market at the present time.

53. PERCENTAGE OF FAILURE AS A CRITERION OF REJECTION OF INSULATORS

This would seem to be a very good rule but it may not be desirable to apply it blindly. The full significance of the tests is not yet evident. In considering the failure of insulators we must take into account the nature of the weakness. Weakness from under-firing porcelain may be more serious than weakness from over-firing. Under-fired porcelain is liable to be uniformly weak all the way through. Over-fired porcelain is liable to be weak in local spots such as cracks.

To illustrate this point examples are taken from a number of endurance runs that were made on insulators which by examination showed thorough vitrification and a tendency to the side of over-firing.

Type X. Of three insulators, one failed in one min. (33 per cent) two were not punctured in 1 hour of test.

Type Y. Of eight insulators, three failed in one min. (37 per cent) five were not punctured in 1 hour of test.

Type Z. Of three insulators, none failed in one min. (0 per cent) all withstood 1 hour.

Type D. Of three insulators, none failed in one min. (0 per cent) all withstood 1 hour.

The experience of the Types X and Y in the above tabulation, although limited, would indicate that some caution should be taken in the rejection of insulators. It may even be that a high percentage of loss may be a good criterion of choice under certain conditions of over-firing. A hypothetical case will be given for illustration: The temperatures in the different parts of a kiln and the time of application of the vitrifying temperature must necessarily vary. The intensely hot flames enter at certain points and the partially cooled flames leave at other points. Both of these places cannot be at exactly the same temperature. Even assuming a final negligible difference of temperature, the porcelain nearest the entering flame must be at a vitrifying temperature somewhat longer than the porcelain near the flues. The cracks in such over-fired porcelain produce dielectric weakness and the insulators are therefore easily detected when tested, and rejected.

We may deduce that a considerable percentage of over-fired porcelain may indicate that the rest of the kiln-ful is perfectly fired. On the other hand, a temperature that will just properly vitrify the hottest spots in the furnace may leave the larger percentage of insulators at a low grade of vitrification. Their dielectric strength may be barely sufficient to pass the usual test and therefore from a standpoint of dielectric strength they are inferior insulators to the hypothetical lot that was rejected on the basis of 3 per cent failure. It is intended here only to point out that more must be known of the intimate history of a porcelain insulator to judge its worth on the basis of a percentage rejection. Intrinsic mechanical strains, layers of flint, relative conditions and rapidity of drying of a batch of insulators, rate of firing, etc. must be known to give proper weight to the basis of rejection by percentage failure.

54. WELDING UP THE PUNCTURE HOLES IN PORCELAIN BY THE APPLICATION OF HIGH-FREQUENCY WAVE TRAINS

Under certain conditions of puncture it has been found practicable to repeatedly puncture and weld up the puncture holes in porcelain. This may not be entirely unknown in tests with 60 cycles although no such experience has been had by the author. There seem to be certain requirements to successfully weld up the holes without failure. The best results were obtained by Mr. Cermak in the tests of large porcelain cups which were made up of several different kinds of clay but all fired at the same time. These cups were partially filled with water which acted as one electrode and the other electrode was a wire wrapped around the outside. The punctures noted never took place directly under the wire and therefore no copper vapor was carried directly into the puncture hole. Since the other electrode was water, no metallic vapor could be obtained from this source. The time of application was varied considerably but three seconds on an average would give good results. The punctured spots in this porcelain appeared as a small bead of clear glass which actually had greater dielectric strength than the porcelain elsewhere, as no welded punctures were repunctured by a second application of potential. No doubt the content of feldspar in the porcelain will have an effect on ease of formation of glass or glaze in the punctured holes.

In other porcelain in which different ingredients were used and which seemed to be less homogeneous, cracks were caused which of course could not be welded up by the high frequency arc. It is very probable that welding up of punctured holes by 60-cycle tests is not common because the punctures are more liable to take place directly between the electrodes and therefore become filled with metallic vapor which leaves the melted porcelain in the path of the arc of weak dielectric strength. The use of the high frequency produces widely extended corona and thereby picks out flaws or weaknesses which are frequently some distance away from the electrodes and thereby avoids the deposit of metallic vapor in the punctured holes. When punctures are made under oil there have been no cases of welding up of the punctured holes due probably to the carbonization of the oil which is always found in the punctured streak.

55. COMPARATIVE PUNCTURE VOLTAGES OF PORCELAIN TO GLASS. PORCELAIN PIECES OF DIFFERENT THICKNESSES WERE USED BUT THE GLASS WAS BUILT UP OF PANES PILED ONE ON TOP OF THE OTHER

The results of these tests are shown in Fig. 28. Curve 1 was made taking puncture potential on glass of increasing thicknesses.

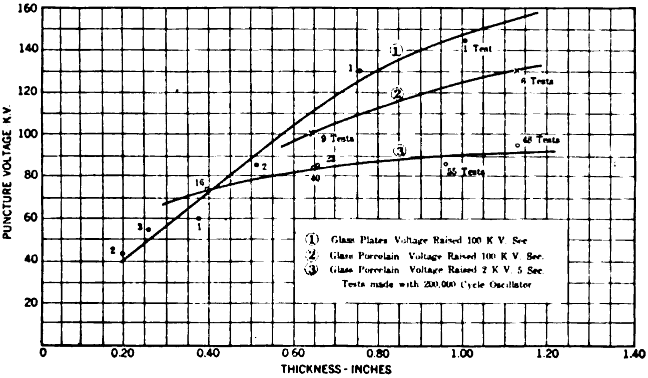


FIG. 28

Comparative puncture tests of glass and porcelain. The connections were made as shown in Fig. 18. Relations are shown of thickness versus puncture voltage. In Curve 1, the thickness of glass was obtained by building up sheets of glass with a thin film of oil between. The voltage was raised at the rate of 100 kv. per second. The small numbers placed near the points represent the total number of tests made at the different thicknesses.

Curve 2, made from porcelain of different thicknesses with the voltage raised at 100 kv. per second, the same as in the glass.

Curve 3 is also from porcelain and differs from Curve 2 only by having a slower rate of increase in the voltage. It was increased at the rate of 2 kv. every five seconds or 1/5 kv. per second. Curve 3 will be seen to give the results of an average of many tests on bushings with corrugated surfaces.

Each individual thickness of the glass was 1/16 in. and each piece of glass was immersed in oil before it was pressed against the adjacent sheet which of course left a thin film of oil between the plates of glass. The curve shows an almost direct increase of puncture potential with an increase of thickness.

Curve 2 has only two points—one the average of six tests at 1.2 in. thickness and the other an average of nine tests at 0.62 in. thick. The tests which gave the data for curve 2 had a more rapid rise in the testing potential than the tests of curve 3. The porcelain also differed. The higher puncture potential may be credited to both of these conditions, namely different porcelain and more rapid increase of testing potential.

The points of curve 3 are the average of 182 tests total and therefore may be considered a fair average of the porcelain which we had at hand. An important result shown by this curve is that increase in thickness of porcelain from 0.4 in. to three times as much or 1.2 in. gives an increase in puncture potential from only 74 kv. to 91 kv. which is 13 per cent. Three hundred per cent increase in thickness gives 13 per cent increase in puncture potential. Although this general condition of increasing the thickness without increasing the puncture potential is known, the small percentage of gain from an increase in thickness may be new to many.

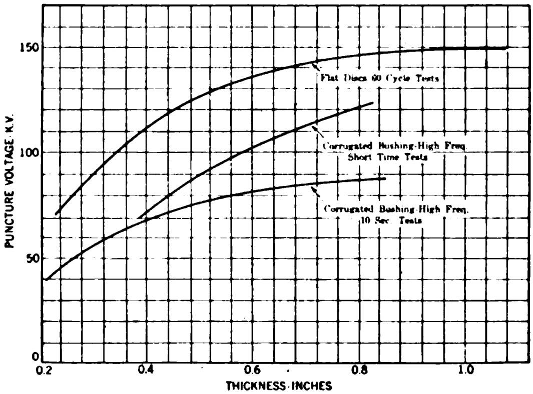


FIG. 29

Puncture voltage of porcelain. Thickness versus puncture voltage. Curves to illustrate the effects of irregular surfaces of the porcelains and shape of electrode as they influence the puncture voltage. The upper curve is a reproduction of 60-cycle tests on flat disks. The lower curves are the same as given in the previous figure.

56. COMMENTS ON THE CHOICE OF THE FORM OF THE TEST PIECES OF PORCELAIN

It has been the custom of previous investigators on porcelain to have made up in the porcelain factory plain disks of varying thickness on which the puncture potential tests were made. These plain disks of porcelain involve the easiest conditions of manufacture, both the drying and the firing being possible with a minimum resultant strain from shrinkage in the body of the porcelain. Consequently the puncture potential shown by these investigators is necessarily very much higher than shown in either curves 2 or 3 of Fig. 28. Such a curve taken at 60 cycles impressed is shown in Fig. 29, taken from results published by W.

F. Fellenberg, together with our average curve of Fig. 28. Any careful designer would take a factor of safety on the values obtained from the tests of such disks which would bring the working values even less than curve 3. The form of the porcelain part is a very important factor in the resultant dielectric strength and therefore it seems permissible to make tests on the actual porcelain ~~parts~~ irregular as they may be. In order to decrease the cost of such tests, comparatively small electrodes were used, a copper strip 0.12 in. thick and 2 in. wide rounded at the surfaces that come in contact with the porcelain, and these electrodes were moved from point to point on the porcelain part tested. By getting a great number of tests a much better average value could be obtained than from a dependence on a single test. Knowing that the small electrodes would cause a high potential gradient at the surface of the porcelain this practise may well be brought into question. I believe it is justified, however, by the fact that in testing either a bushing or an insulator in air corona sparks creep out over the surface and the dimensions of such a spark are comparable to that of the electrodes we employed. Therefore, the potential gradient at the surface of such a spark might be at least as great as that produced by the strip electrode that we used. The corona is evenly spread over the surface of an insulator near the caps and pins and therefore there would not be the sharp outline of a spark. There is, however, at the end of the pin and at the edge of the cap of a suspension type insulator the same concentration of potential gradients. On the whole we conclude that the use of the narrow electrode for testing under oil up to 90 kv. is justifiable in the condition in which it is used and gives reliable results. For higher voltages the time of application of voltage must be made very short to limit local damage by potential gradient. Some illustrative tests of this point are given later.

57. The Relation of Puncture Voltage to Thickness of Porcelain for Different Mixes and Firings

There are three curves given in Fig. 30 showing the puncture potential of three different mixes of porcelain. The upper curve and the lower curve of the three are the puncture potentials taken on suspension type insulators and the middle curve on corrugated bushings. Therefore there exists a difference in form as well as a difference in material. The results show that there is no very wide variation between the different mixes of clay although the color varied from a pure or bluish white to a light yellow. The porcelain which gives the lowest puncture voltage in the curves of Fig. 30 had previously given in other samples tested through the head even better dielectric strength than the samples which gave the data for the upper curve. The weakness may be attributed to the shrinkage strains coming from the presence of the petticoats on the skirt where the voltage was applied. So far as the study has been carried it would seem that the different manufacturers of porcelain have their ups-and-downs of luck and while one mix will be found high in dielectric strength at one time due to having the several factors of porcelain manufacture combined under favorable conditions, they will have other periods when poor combinations will take place and the porcelain will run a little lower in dielectric strength. It would seem that "eternal vigilance" is the price of obtaining a uniformly good product. In making designs of porcelain it is essential to use the puncture potential corresponding to the minimum average that a porcelain factory can produce.

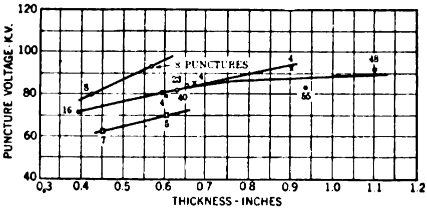


FIG. 30

A comparison of the average puncture potentials of a number of different mixes of porcelain. All tests were made on irregular surfaces. The numbers at the points represent the total number of tests made for each thickness.

58. THE TECHNIQUE OF DEVELOPMENT OF FAULTS AND PUNCTURES IN PORCELAIN AND METHODS OF EXAMINATION

When porcelain punctures, the current may cause a single streak or it may cause a crack and, if so, the discharge usually flattens out in the crack, dividing into several paths. If the puncture occurs under oil the current will usually carry oil with it, which is carbonized in the heat of vapor of the electrodes, and both together produce a black streak which is easily seen after the porcelain is broken into pieces. The marking depends somewhat on the duration the discharge is allowed to play through the puncture.

After the porcelain is broken up the hammer blows or pressure which is used to break it up will produce cleavage surfaces and cracks which did not exist in the porcelain before it was smashed. It is important to determine what cracks existed before the electrical test was made, what cracks were produced by the electrical test, and their extent, and what closed laminations existed in the porcelain. These three faults should be differentiated from the cracks resulting from the mechanical destruction of the porcelain piece. Otherwise stated: after a piece of porcelain is smashed to pieces it is in general impossible without a preliminary stain to detect the cause of the different cracks which appear.

The following technique has been used to advantage in the examination of the porcelains and in most cases has indicated the nature of the fault. In many cases the cause of the fault has been traced to a particular condition of manufacture which needs to be improved. In beginning the tests of a piece of porcelain, then the first step is to determine the presence of accidental flaws so far as possible. Soaking in eosin stain or aniline violet dissolved in alcohol, under vacuum, allows the penetration of the stain into the open air-pockets and laminations. A dark stain may be used for this purpose. The stain is then washed off the surface of the insulator. Frequently the cracks will be shown up by the streaks where the stain has soaked into them and will not wash off. The insulator is then dried and punctured under oil. It is removed from the oil and the oil is washed out with gasoline or some other solvent of oil. The insulator is then thoroughly dried at a temperature above 100 deg. It is then immersed in red aniline stain (alcohol solution) and placed under a vacuum. The red stain will penetrate most of the holes and cracks that are opened up by the punctures. In removing the insulator from the stain it is wiped off, and washed off and dried, to prevent discoloration later in handling the broken pieces. The porcelain is then broken up. The original cracks are shown by the dark stain with a layer of red stain on top and the developed cracks are shown by the red stain alone. In some cases it is found difficult or impossible to remove the oil from a crack and this oil will be found on the surface of the crack as an indicator that the crack was produced by the discharge. Any surface of a broken piece which shows neither stain nor oil, it is natural to infer, is produced by the mechanical strains of the hammer or vise. The alcohol solutions are far more penetrating than solutions in water, such as ink.

59. Closed Pores and Bubbles, Known as "Blebs"

In the glazes on electrical porcelain, so far examined under a microscope, all have contained bubbles which have the same appearance as the familiar bubbles in common glass. A magnifying glass is sufficient to bring these to view but a magnifying power of 50 is desirable for careful examination. A magnifying power of 250 diameters usually obscures them because the focus is of such short range that only a part of a bubble can be seen with one setting of the lenses. They are more easily seen and studied in colored glazes than in the clear glaze. The size of the bubble and the number of them differ in the glazes from different manufacturers,—in fact they differ in number on the same piece of porcelain. On ridges the glaze is liable to run thin; in the valleys of corrugations it is much thicker and as many as three bubbles can be found at the same position of the microscope at different depths in the glass. These bubbles are apparently formed by a boiling of the glaze at the temperature of 1310 deg. cent.

No significance has been attributed to them so far, but our very recent experiments on the beginning of failure, as given later under tests with potential gradient, indicate that under certain conditions these bubbles may play a not unimportant part in the failure of the porcelain back of them.

The bubbles being formed at high temperature, the gas they contain must be at a partial vacuum and therefore easy to ionize by the application of voltage.

When these blebs appear in the body of the porcelain it is natural to infer that either too much feldspar or other flux has been used, or the temperature of the kiln was carried too high for the ingredients of the porcelain. It is rare indeed that visible "blebs" are found in electrical porcelain outside the factory. Perhaps this is because such pieces will be so soft at the high temperature that they will warp out of shape, and consquently they will be scrapped during the first visual inspection as they are taken from the kiln.

An unusual form of bleb has been found in one kind of porcelain for which no definite explanation has yet been found. The bubbles are of varying size, all visible with the naked eyes, and some of them are as large as one millimeter in diameter. These pockets or bubbles at the surface of a broken piece of porcelain were filled with eosin stain dissolved in alcohol and after thoroughly drying the stain the edge surface of the porcelain was ground off, thus decreasing the depth of bubble. It was found that the stain has soaked into the walls of the bubble to a depth greater than the diameter of the bubble. Here is an odd bleb surrounded by open pores. The porcelain was made in an experimental way and the bleb might have been due to a free flux as distinguished from a flux like feldspar in which the potash is bound up chemically until a high temperature is reached in the kiln.

Ceramists state that even the best porcelain contains minute cavities or pores of microscopic dimensions. This structure may be called the natural one for porcelain and the term " bleb " does not apply to it. It is probable that the granular or flaky structure of the porcelain is the characteristic that makes it less brittle than glass.

60. The Hot and Cold Test

Strains and laminations will usually be developed by a hot and cold test on the porcelain. This test has been used by a number of investigators and consists of transferring the porcelain periodically from boiling water to cold water. After a few transferences of this kind the insulator can then be soaked in stain under a vacuum to mark the cracked surfaces. A partial crack developed in this way will be completely developed by a high-potential high-frequency test. A complete crack from suface to surface of the porcelain will be indicated by a megger test. By using the megger test first it is possible to distinguish between partial cracks and complete cracks.

Regarding the question of the fairness of the hot and cold tests, we must again look to the conditions which occur in practise. It sometimes happens in certain climates that a hail storm will occur on a very hot day. The insulator and pin are at or above atmospheric temperature and a shower of hail or equivalent ice-cold water falls on the top of the insulator. This cools the upper exposed surface, leaving the lower ones warm. In the winter-time it occasionally happens that the temperature will change from a low value into a warm rain. This gives the insulator the other extreme of change of temperature.

It would seem from these two conditions that a hot and cold test carried over a range somewhat greater than that which may occur in practise is a justifiable test. It should be noted that the hot and cold test may develop mechanical strains in the porcelain which are present but normally are not faults. It is conceivable that a hot and cold test may produce strains and faults which did not exist before the temperature changes took place, due to a lack of elasticity in the porcelain and cement. Unless there is air in the porcelain it has not yet been determined whether such latent faults would always be developed with certainty by the electrical test, although the tests given would indicate that they would be. Theoretically the electrical test should strain the porcelain mechanically and might develop the faults. It should be recalled that we have shown by Fig. 23 that the electrical test when carried to the limit develops a puncture along those lines where shrinkage strains were greatest. Everything else being equal, we may tentatively infer from these tests that the shrinkage strains decreased the dielectric strength about 30 per cent.

61. Hot and Cold Tests Applied to Suspension Type Disks

Insulators from three different manufacturers, foreign and domestic, were used. The insulators were carefully tested to arc-over value and showed no puncture. The first set of hot and cold tests consisted in placing the insulators first in water at 66 deg. cent. and then in water at 9 deg. cent. for periods of 10 minutes each. Four insulators total were tested and none of them was cracked by this test.

In the next test the insulators were plunged into hot water at 100 deg. cent. for five minutes, then taken out and allowed to cool. In a subsequent test the voltage was not carried up to arc-over value but sufficiently high to give heavy corona discharge with potential from the oscillator. One of the four insulators punctured. We will designate these four insulators by A, B, C, and D.

Insulator D, the punctured one, was replaced by insulator D-1. The four insulators were again immersed in boiling water for 10 minutes, then plunged into cold water at 9 deg. cent. for 10 minutes. Insulator D-1 punctured under subsequent tests. Three more insulators were now added, which will be designated by B-1, C-1, and D-2. These insulators were then alternately immersed three times in boiling and three times in cold water at 9 deg. cent., each for 10 minutes. It was found that D-2 was punctured but all the others were normal. Insulators D-3 and D-4 were now added and all of them were again placed in boiling water for three minutes and in cold water immediately afterwards, and then tested. In this case no punctures were produced.

It should be noted that the insulators designated by C and D were made by one manufacturer and the difference in their ability to withstand the temperature changes was due to the form and vitrification of the porcelain and certainly not to the ingredients.

62. ADDITIONAL TESTS TO DETERMINE THE QUALITY OF PORCELAIN

Space does not permit of a description of other tests which have been made to determine the quality of porcelain, since it is desired here to show particularly the application of the oscillator and the new results which may be obtained with it. These other tests, however, are of varying importance and may possibly be given later. For example, the mechanical impact test with a varying weight is important in determining the fragility of the porcelain. Of the other tests along this line are the *ring of porcelain when struck*, *tensile strength*, *compressive strength*, *abrasive resistance*, tests for *toughness or brittleness*, *x-ray tests*, *microscopic investigation* with etching, *dielectric constant* as a basis of comparison, *absorption tests*, .and so forth.

63. TESTS WITH CONTINUOUS HIGH FREQUENCY FROM AN ALEXANDERSON ALTERNATOR

It seems desirable to distinguish at this time between the results obtained by high-frequency wave trains such as are generated by the oscillator and continuous high frequency as generated by an alternator giving 100,000 to 200,000 cycles continuously. In practise there is no known strain on insulators corresponding to a continuous high frequency. Therefore there is no reason for using the high-frequency alternator in a standard test, much less so in fact than using 60 cycles as a standard test for insulators. However, the high-frequency alternator can be used in special tests to determine dielectric losses.

64. TESTING WITH WIRELESS OUTFITS

The usual apparatus used in sending wireless messages produces a series of wave trains of somewhat the same form as the oscillator already described. It is usual, however, to use a frequency of several hundred cycles per second in place of the 60 cycles per second. This gives a little more heating than an equal voltage furnished from the oscillator. There is a considerable difference in the practical handling of the two methods.

65. COMPARISON OF SMOOTH AND CORRUGATED SURFACED BUSHINGS

It is well known among designers that corrugation and petticoats on the surface of bushings increase the spark voltage. The following study was made to determine the laws of variation of spark voltage with increase of length of bushing, both smooth and corrugated.

Four test samples were used. No. 1 corresponding to curve 1, Fig. 31, was a porcelain bushing one inch thick, having a depth of corrugation of ¼ in. The thickness of porcelain in all of this data is always measured at the minimum point, that is to say, at the deepest part of the corrugation.

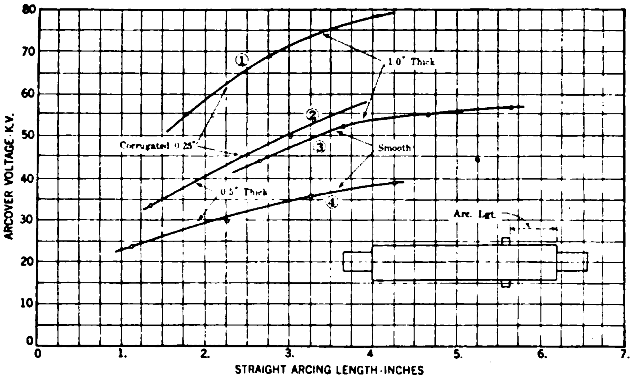


FIG. 31
The relation of length and thickness to the arc-over voltage in air of porcelain bushings and also a comparison of smooth and corrugated surfaces. Tests made with the oscillator. The relation is given between straight arcing length in inches versus the kilovolts arc-over voltage.

Test piece No. 2, corresponding to curve No. 2, was ½ in. thick with ¼ in. corrugations.

Test piece No. 3, corresponding to curve 3, had a thickness of one inch and a smooth surface.

Test piece No. 4, corresponding to curve 4, had a thickness of 1/2 in., and a smooth surface. These curves show the relation between the arc-over voltage and the arc length measured straight from electrode to the end of the test piece, but not taking into account the increased length due to corrugation and thickness at the end. The tests were made by placing a metal rod inside the porcelain bushing and placing a metal ring around the porcelain at different distances from the end to give different spark lengths in air along the surface of the porcelain.

To compare the corrugated to the smooth porcelain, curves 1 and 3 may be used, both having one in. thickness of porcelain, or curve 2 may be compared to curve 4, both pieces having 1/2 in. thickness. The effect of thickness can be obtained by comparing curve 1 and curve 2, both of which are corrugated but of different thickness; or by comparing curve 3 and 4, both of which are smooth but of different thickness. As an example it is seen that for an arcing length of 3 1/2 in. and a thickness of one in., the arc-over voltage for a smooth surface bushing is 52 kv. Corrugating this surface with ridges 1/4 in. high raises the spark potential to 77 kv. From these data the relative effect of the corrugations can be seen. This relative value of corrugating is brought out by making comparisons of the spark-over voltages for different arc lengths at any desired point.

66. Study of Arc-Over Voltage of Bushing, Using Super-Spark Potential from the Oscillator

All the studies so far carried out have been on the basis of producing a design of porcelain of sufficient dielectric strength to withstand the voltages necessary to cause an arc-over when the applied voltage is gradually raised. This is the condition in the standard practise of testing as carried out today.

We are now to look forward to a more ideal design of insulators in which the requirements are going to be very much more severe. In practise, insulators are subjected to momentary lightning surges in which the potential may be very much above the value necessary to produce a spark. This high potential is very quickly relieved by the movement of the lightning surge along the circuit. If the relief is sufficiently rapid the super-spark potential may be applied to the insulator without causing an arc-over simply because the arc has not had time to form. In line insulators it is absolutely essential that this super-spark potential shall not cause a puncture from electrode to electrode through the porcelain. The brief time required to puncture the porcelain must be greater than the time necessary to form the creepage spark around the skirts of the insulator through the air; otherwise a puncture will be produced.

In the case of porcelain bushings, the problem is somewhat different from the design of a line insulator. This difference comes from the fact that the porcelain bushing is used on a definite piece of electrical apparatus such as a transformer, motor, potential regulator, meter, etc. and there is need of a lightning arrester at this point. If it is possible and reasonable to do so, a porcelain bushing should also be designed with the criterion that it should always arc over before it punctures. We shall see later that this may lead to great difficulties and it may be deemed advisable by the designer to use a different basis. Since the bushing is protected by a lightning arrester in the neighborhood it should be possible to find a factor of safety against puncture of the porcelain which is sufficiently high to be above the maximum potential that can exist across the bushing as limited by the lightning arrester. At the present time this factor of safety is unknown due principally to the lack of information regarding the voltages which may come from local oscillations, such as would create momentarily a higher voltage at the bushing than exist at the terminal of the lightning arrester. It is impossible to place all the lightning arresters quite near all the bushings which they are to protect. However, it is a tenable hypothesis that a factor of safety can be chosen which will put the spark potential of the porcelain bushing above the maximum potential that can exist across the lightning arrester for any intensity of discharge, with the exception of a direct stroke. If this standard of design is adopted a bushing may be used which cannot be tested to the voltage which would cause an arc-over. In other words, in a long bushing with much exposed surface to mitigate bad effects of dust collection, the requirements of test shall be changed to suit these new conditions. The test should then carry the test voltage up to a value corresponding to the factor of safety chosen, say three or four. Nevertheless, the same standard made for the insulator is desirable for the bushing if it can be attained practically. To summarize then, line insulators which have no lightning arrester protection must of necessity be designed so as to withstand a super-spark potential without puncturing, being always protected by an arc over the surface of the porcelain.

The plan is now to make an experimental investigation of what conditions must exist in porcelain bushings in order that the super-spark potential shall cause an arc-over rather than a puncture.

The first test is made on a smooth surface bushing $\frac{3}{8}$ in. thick and a length along the surface of 1.9 in. The generated potential of the oscillator was gradually raised in successive steps from the arc-over voltage (27 kv.) to its maximum value of 170 kv. corresponding to 10 kv. on the control gap shown as abscissas in Fig. 32. As the momentary impressed potential is increased from 27 kv. to double that amount the gap in parallel with the bushing shows an increase in potential from 27 kv. to 32 kv. This increase of 19 per cent in the equivalent spark voltage at the terminal of the bushing for 100 per cent increase in the applied super-spark-voltage represents a logarithmic time curve of discharge, the time decreasing rapidly with the increase in voltage. When the super-spark potential has been increased 24 times the arc-over potential, the equivalent gap in parallel with the bushing shows a maximum rise of voltage to 50 kv. which is slightly less than twice the arc-over voltage.

From the point of 24 times the arc-over voltage, to the super-spark potential of 40 times the arc-over voltage, the equivalent gap in parallel with the bushing increases only 2 kv. more. In other words, the maximum possible potential that may be impressed on this bushing is of the order of double the arc-over potential. We might look forward at this time to our method of design. If we were choosing the thickness of this bushing for a design that would withstand super-spark potential without puncture we would turn to a puncture curve of porcelain under oil and choose from this curve a thickness and grade of porcelain which would not puncture on 50 kv. applied. This bushing would then arc over for super-spark potentials of 175 kv. at 300,000 cycles and should be proof against puncture.

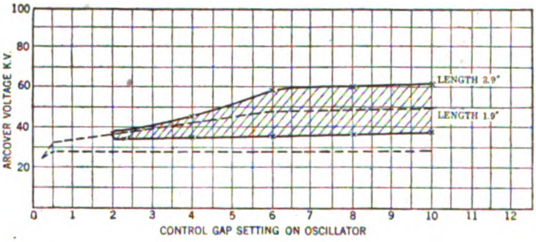


FIG. 32

The relation of arc-over voltage on a smooth porcelain bushing 0.38 in. thick when voltages above the spark voltage, that is, super-spark voltage, is applied. Tests made with the oscillator. Relation is shown of control gap setting versus arc-over voltage as measured by a gap in parallel with porcelain bushing. Control gap setting corresponding to the maximum voltage generated in the coreless transformer. This maximum voltage generated is considerably above the values measured by the gap when the voltage is above minimum value that will cause an arc-over. Two different sets of curves are shown. Each curve has two branches. The upper branch represents the maximum gap which causes all the discharge to take place across the bushing in parallel. The lower branch shows the maximum gap setting which will just take away all discharges from the bushing in parallel.

In this same set of tests another factor was studied, namely the factor usually determined in the design of lightning arresters. What gap must be placed in parallel with the bushing such that the discharge will always take place over the parallel gap rather than over the bushing? In terms of lightning arrester design, what equivalent gap must a lightning arrester have so that it will always take the discharge of high potentials away from a bushing and thereby give it protection from arc-over? In Fig. 32 the lower branch of the curve shows a practically constant voltage setting of 28 kv. on the gap to take the discharge even when the super-spark potential was as great as 175 kv.

In the next step the length of the same smooth surface bushing was increased from 1.9 in. to 3.9 in. The same system of tests was applied and is shown (Fig. 32) in the corresponding pair of curves with cross hatching between them. There is one feature of special note shown by this curve which is different from the previous one. The lower part of the curve, that is the parallel gap which will protect the bushing from arcing over, is considerably less than the arc-over voltage of the bushing. For example, the arc-over voltage is 38 kv. With a super-spark potential of twice the arc-over potential the gap must be reduced from 38 kv. to 34 kv. in order to take the spark away from the bushing. Again this curve shows a change of direction at a point on the control gap marked 6 kv., corresponding to about 100 kv. momentarily impressed on the gap. We must not conclude that the curves representing the equivalent gap in voltage are actual voltage. It is impossible in the present state of knowledge to accurately state what the impressed voltage is from the setting of the spark gap. The dielectric spark lag enters therein, and is affected by various conditions. We must take into account also that the impressed frequency in this case is about 300,000 cycles and that the equivalent gap would change somewhat by a change in the frequency, this being due to a relation between the wave front and the dielectric spark lag of the gap.

67. FURTHER TESTS WITH SUPER-SPARK POTENTIAL

In Fig. 33 are shown two sets of curves taken on bushings with corrugated surface. The sparking length of bushing in the lower curve was 1.75 in. and in the upper curve 3.9 in.

As before, the abscissas are proportional to the applied super-spark potential and the ordinates represent the potential as measured by the sphere gap. There are two curves for each setting of the super-spark potential, one minimum equivalent gap which takes all the discharge and one maximum equivalent gap in which all the discharge is transferred to the bushing which is connected in parallel with the gap.

These curves show the same general outlines as the previous tests on smooth-surface bushings. The corrugated bushings, however, show a very much higher test of voltage which is due to the greater difficulty in forming a creepage spark over the hills and valleys of the corrugations. The spark will run over the outside surface, parallel to the conductor in the center of the bushing, fairly easily, but when it has to climb one of the ridges of the corrugation at a considerable angle to the central conductor it requires a very much higher voltage to produce the creepage spark. Once over the ridge the spark can again dart down into the valley of the corrugation with ease but is again retarded as it climbs the next ridge of the corrugation. This condition has been illustrated elsewhere and it does not seem necessary to reproduce the illustrations at the present time.

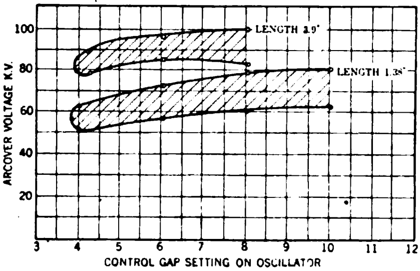


FIG. 33

These relations are entirely similar in every respect to the curves given in Fig. 32 except that the thickness of the bushing was one in. and the surface was corrugated with ridges 0.25 in. high. (In the lower branch of the upper curve, at 6 kv. setting on the control gap, is an error. It should be 82 kv.)

FORMULAS FOR THE LAWS OF VARIATION OF SUPER-SPARK POTENTIAL VERSUS ARCING LENGTH ON CORRUGATED BUSHINGS

Many tests were made on different forms of insulators and it was found that the law of creepage spark was usually of the nature of an exponential curve within the range of lengths and thicknesses studied. The different formulas need checking in extrapolated points and for this reason they are not published at the present time. The points given for the curves of super-spark potential fall approximately on a straight line when plotted

on logarithmic paper. The curves are represented by the following formula:
$V = 50\, t^{0 \cdot 682}\, L^{1 \cdot 05}$ (porcelain corrugated)
V = Maximum measured super-spark voltage in kv.
t = Minimum thickness in inches
L = Distance from outer terminal to end of bushing in inches.

68. TESTING OF STRINGS OF INSULATORS WITH THE 300-KV. OSCILLATOR

When the problem of testing disk insulators in strings is undertaken the oscillator shows some marked advantages over the 60-cycle method. The oscillator has dimensions and cost which are only a small fraction of a 60-cycle outfit. In designing 60-cycle transformers there is nothing gained by using extremely small wire and therefore the dimensions of the transfomer for a voltage of 500 kv. to 750 kv. are necessarily comparatively large.

The several insulator disks in series in the suspension type insulator have separated electrodes which give what may be called the multi-gap effect, each iron electrode on the insulators having a capacitance to ground as well as to the adjacent one. This theory was first explained by Dr. Steinmetz in 1906 in relation to the multi-gap arrester. He showed that the concentration of voltage at the end gaps of the lightning arresters was due to the capacitance of each metal cylinder to ground. It is now common knowledge that the same condition exists in a string of suspension insulators and the voltage is unevenly distributed throughout the string, as has been shown by several investigators. The disk next to the line takes the largest percentage of voltage.

After noting this theory, it is somewhat confusing to find that in testing a string of insulators it is not the end disks which are most liable to puncture. Some tests were made which show that the insulator farthest from the end is the one most frequently punctured by the high frequency wave trains from the oscillator. Five insulators were placed in series and connected to the oscillators having no ground at either end. This places the third insulator at zero or earth potential. Out of 21 insulators punctured 13 of these were in the location of the third disk, four were in the location of the second disk, and two in the corresponding symmetrical location of the fourth disk. There was only one insulator at each end of the string that was punctured in all the tests Making comparisons between these different conditions, the middle disk of a string of five punctured 13 times as many times as the end insulators. It also punctured 3 to 6 times as many times as the adjacent disks on each side of it.

The explanation of this phenomenon seems to be that of difference in super-spark potential on the disks in the different locations. As a tentative explanation the following is given: When the high voltage high frequency is applied to this string of insulators the distribution of potential gives the greatest potential at the end disk and the least at the middle disk. However, the total voltage applied to the end disks is not extremely high because of the partial distribution along the string. The applied voltage is somewhat higher than the value necessary to cause a spark. The end disk sparks over and there is thrown suddenly on the three remaining disks a super-spark potential of considerable value due to the short-circuiting of the end disk by the spark. The duration of time considered is of the order probably of a few millionths of a second. The total voltage applied in these tests, approximately 350 kv., is now divided somewhat unequally between the three disks. If the second and fourth disks are not punctured by this excess voltage they will spark over and the middle disk for a moment will receive a voltage of nearly the full value of 350 kv. As a result the middle disk is very liable to be injured.

The effect obtained by the concentration of voltage on the end disks and their successive elimination by sparking around the skirts of the disks is very much like using one insulator on this oscillator and suddenly discharging against it an impulse of 350 kv. The actual spark potential of the disk is about 85 kv. which leaves a super-spark potential of 265 kv. This effect is exactly like the one obtained from a lightning stroke on the line. I think it very probable that operators of transmission lines can confirm the statement that lightning does damage disks from time to time that are nearer the ground terminal than the line terminal of the string of disks.

It is important to add further information in regard to the duration of the tests. In each case the 60-cycle potential was applied to the oscillator for a period of five seconds. The test was then discontinued for five seconds, giving the insulators a rest, and then re-applied. In order to puncture the middle insulator the number of applications of five seconds duration are given as follows: 8, 7, 21, 9, 1, 18, 4, 50, 18, 16, 10, 8, 1.

The number of applications of five seconds each to puncture the six adjacent disks, namely the second and fourth in the string were as follows: 30, 1, 39, 16, 8, 3. For the end disks, namely the first and the fifth, there were 9 and 11 applications of five seconds duration. Each second represents 120 wave trains applied to the insulator so that each application, as given in the above list, means 600 wave trains discharged against the string.

In the data given above there is no statement made of the number of times that the impulses were applied without causing damage. The method of test was to continue to apply the voltage to the string of insulators for five-second periods until at least 50 applications could be made without damage to the string of insulators. Then a new string was installed and as fast as the disks were punctured they were replaced until the string showed its ability to withstand the tests. In the first string there were 50 applications of five seconds duration finally applied without causing damage. In the second string 120 applications were finally made without causing punctures. In the third string there were also 120 applications without causing puncture. In the fourth string of insulators there were 50 applications without causing puncture. These tests tend to show that the insulators are designed so that they can withstand this test. It is an extremely severe test and under present conditions of knowledge and manufacture it would seem to be unfair by being unduly severe. The tests are given not as recommendations but as information on the subject.

In regard to the location of the punctures; 50 per cent took place in the head of the disk and 50 per cent at an average distance of one in. out on the porcelain skirt. Another series of tests was made in which the duration was only ½ second with two-second intervals of rest. It was found that a shorter duration was of very much less severity to the porcelain than the longer duration. Damage is therefore being done to the porcelain in a manner which will be illustrated later under potential gradient tests. While the arc-over potential of these disks was in the neighborhood of 85 kv. the puncture potential under oil was 128 kv. and 150 kv. which gives a factor of 150 per cent and 176 per cent. The study of the necessary dielectric strength to puncture, similar to the one already given for bushings could be made with an oscillator and thereby determine what factor is necessary in order that the suspension disks shall always spark around the skirts rather than puncture. No previous tests were made under oil on any of the disks that punctured to determine if their factor of safety was as high as the two given above. It is desired at the moment simply to point out that it is a comparatively easy investigation to make with the oscillator although precaution must be taken to limit the duration of the test to the value that will not cause local damage to the porcelain by corona in accordance with the values determined from the potential gradient tests, examples of which are given later.

69. POTENTIAL GRADIENT TESTS WITH THE OSCILLATOR NOT CARRIED TO PUNCTURE OF THE PORCELAIN PIECE

Test piece was a porcelain bushing, 13 14/16 in. long with a minimum diameter of 3 10/16 in. outside and 1 6/16 in. inside approximately. The thickness of the porcelain was 0.94 in. From bottom to top, as it stood in drying and in firing, there are eleven grooves on the lower half and nine grooves on the upper half. The tests were started on the top groove, No. 20. Inside the porcelain tube an iron pipe was placed and on the outside was placed our standard electrode which is 0.12 in. thick and 2 in.. wide rounded at the edges. The porcelain was immersed under transil oil to a depth of 2 in. The duration of application of voltage in every test was five seconds. On the 20th or top groove the first potential applied was 60 kv. and in each succeeding groove, there were 10 kv. added. When 120 kv. was reached and applied for five seconds the porcelain punctured. The detailed results of these tests follows.

TESTS WITH VARIABLE VOLTAGE BUT 5 SECONDS CONSTANT DURATION

Groove. No.	Kv. applied.	Comments
20	60	No visible damage to the surface.
19	70	" " " " " "
18	80	" " " " " "
17	90	A very definite black streak was produced on the ridge.
16	100	Only a very slight marking on the surface.
15	110	More evident damage to the surface.
14	120	The porcelain was punctured and a piece ¼ in. wide was chipped off.
12	60	No visible damage done to the surface.
11	70	" " " " " " "
10	80	Small piece of glaze chipped out on the side of the ridge and a black deposit at the bottom. Length two mm.
9	90	Very visible damage done, chipping out the glaze for about 2 millimeters and producing five definite black spots. There was one puncture hole through a bubble in the glaze and the puncture ran in various directions to the other five spots, all of which are bubbles in the glaze.
8	100	Although the voltage was higher there are only two very small spots where the corona broke through the glaze.
7	110	Again a very appreciable piece four mm. long chipped out of the glaze.
6	120	Punctured, leaving a small black spot, showing a superficial crack about 25 mm. long running across to the next groove.
4	80	No visible damage done to the surface.
3	90	Punctured. A chip about three mm. wide and five mm. long was thrown out of the surface. A crack 10 mm. long was caused by this puncture.
1	100	No visible damage done to the surface.

Further Comments. A microscopic examination was made from 25 diameters to 250 diameters. The damage to the surfaces is done by the combination of potential gradient and heat of the corona. It seems evident from these tests that there is a considerable difference in the dielectric strength of the porcelain in different spots as evidenced by the fact that some, say at 100 kv., did not scar the surface where tests at 90 kv. did. This naturally leads us to the possibility of examining the homogeneity of porcelain by means of potential gradient as distinguished from the ordinary potential tests. Such a study will be described later.

70. POTENTIAL GRADIENT TESTS ON PORCELAIN WITH THE ELECTRODES SO ARRANGED THAT PUNCTURE COULD NOT TAKE PLACE

In the previous test given, the lines of electrostatic force were perpendicular to the surface of the porcelain due to the fact that a long metal electrode was used inside the porcelain bushing and the other electrode was placed against the surface in a valley of a corrugation.

In the test now to be described the internal electrode was removed from the bushing and placed in the oil at a horizotal distance of 9 in. from the center of the porcelain bushing and at about the same distance from the other electrode which rested on the upper surface of the bushing. The lines of electrostatic stress were carried through the porcelain to a certain greater extent than through the oil due to the fact that the dielectric constant of porcelain is about 2½ times that of oil. However, there was no tendency to puncture the main body of the porcelain and the only effect obtained was the intense voltage gradient at the surface of the porcelain on which the small electrode rested.

In the first group of tests the time of application was 10 seconds and the potentials used varied in the seven different grooves tested from 120 kv. down to 70 kv. The general results of these tests were negative, that is to say, no markings were caused by the potentials applied.

In the second group of tests the porcelain bushing was rotated about 80 deg. from its previous position. The time of application of potential in each of the ten tests made was five seconds. The results show the gradual development of faults.

Groove No.	Kv. Applied.	Comments
1	70	No visible damage to the surface.
2	80	No visible damage done to the surface.
3	90	A visible black speck on the glaze of the bottom of the groove.
4	100	" " " " " " " " " " " "
5	110	Slightly larger speck.
6	120	Same size of speck as previous test.
7	130	Same size of speck as previous test.
8	140	Visibly larger speck.
9	150	A black streak about two mm. long. During the test a visible glow was seen through rather dark oil at a depth of 3 in. at the contact of the electrode and the surface of the electrode.

Comparing the second group of tests to the first group, it should be noted that in spite of a reduction of time from ten seconds to five seconds, damage was done at the same voltage which indicates perhaps weaker porcelain.

In the next test which was made on groove 10, the time of application of potential was increased from five seconds to 30 seconds and the voltage was maintained at 150 kv. As a result a black streak about three mm. long was produced on the surface of the porcelain. A microscopic examination showed two puncture holes in the glaze and a black streak running along the surface of the porcelain. The diameter of the punctured holes in the glaze was about equal to the size of the bubbles in the glaze.

In the third group of tests the time was made uniformly 30 seconds for each step. The same angular position was used as in the previous tests but the distance was 3½ in. farther up on the bushing.

Groove No.	Kv. Applied.	Comments
12	100	No visible damage to the surface.
13	120	A glow at the electrode visible through the oil. A streak about 5 mm. long was produced on the side of the ridge. Some glaze was chipped off.
14	140	Same glow as before. Small black speck produced on the side of the ridge.
15	160	Visible glow through the oil. A circular piece about 2 mm. in diameter chipped out of the glaze on the side of the ridge and a streak 10 mm. long extending at an angle down the ridge.

Conclusions. So far as the data go we must conclude that the quality of the porcelain varies at different points of the surface. The damage is apparently done by an extra large displacement current at the surface which causes local heating by the spark. These tests apparently indicate a new method of investigation of homogeneity of porcelain. They have not been carried far enough to determine all the causes of differences found.

71. AN EXAMINATION OF THE SURFACE OF A PORCELAIN BUSHING BY VOLTAGE GRADIENT TESTS

After considerable preliminary work the following basis of test was determined upon. A corrugated porcelain bushing of uniform thickness was immersed in oil with a rod 3/16 in. diameter through the center of it. Around the bushing in the valley of a corrugation was placed a copper wire 0.05 in. diameter. Between these two electrodes there was applied 120 kv. during a period of five seconds, using the oscillator as a source of power. As a result, the voltage gradient at the surface of the wire caused more or less small black spots or scores. The electrode was then moved into the valley of the adjacent corrugation and the test was repeated until all the 20 corrugations were covered. An examination was then made of the surface of the porcelain and it was found that in certain localities there were no spots and in certain other localities there were a considerable number of spots. The development of the surface of the porcelain is shown in Fig. 34 with the location and the relative sizes of the spots.

Since at the start the potential gradient at all parts of the encircling wire was quite uniform these tests show a difference in the dielectric current in the porcelain. The exact nature of this difference is not determined at the time of writing but it is evident that it represents a difference in homogeneity of the porcelain. It cannot be stated that this difference represents a serious or important difference in this particular piece of porcelain. At the same time it would seem that this electrical method would be a convenient one for examining variations in the porcelain as they might be affected by non-homogeneous distribution of ingredients, of drying, or perhaps some other factor.

Knowing that the bubbles in the glaze are the beginning points of the damage to the surface and still further knowing that the expansion of a spark into a bubble would give a greater concentration of voltage gradient at this point, it was thought possible that the beginning of the trouble was due entirely to the accidental location of bubbles in the glaze. While this may be true it was necessary to make further tests to determine if there was a real difference in the quality of the porcelain underneath the glaze. The porcelain bushing was taken to a carborundum wheel and the glaze was carefully ground off in the valleys of the corrugations. The previous tests were then repeated and are shown in the three lower lines of Fig. 34. The damage done in the previous tests was entirely superficial and the black spots disappeared during the grinding off of the glaze. The new spots shown for corrugations 13, 7 and 3 occurred in the same general locality that they did in the previous test when the glaze was present. This tends to prove that the porcelain varies in quality throughout the bushing.

72. When Does the Test Damage Good Porcelain?

It was found in the voltage gradient tests that when the voltages over 100 kv. were applied the damage to the porcelain started in a definite spot and within a few seconds the damage was gradually increased until puncture finally took place. By making a few preliminary trials it was possible to determine roughly the law which determines the voltage and time of application which would damage the surface. These time-voltage applications were then made over the different parts of a porcelain bushing and as a result a certain number of spots were obtained for each application. The spots varied in diameter and somewhat in number. Therefore a certain arbitrary weight was given to the

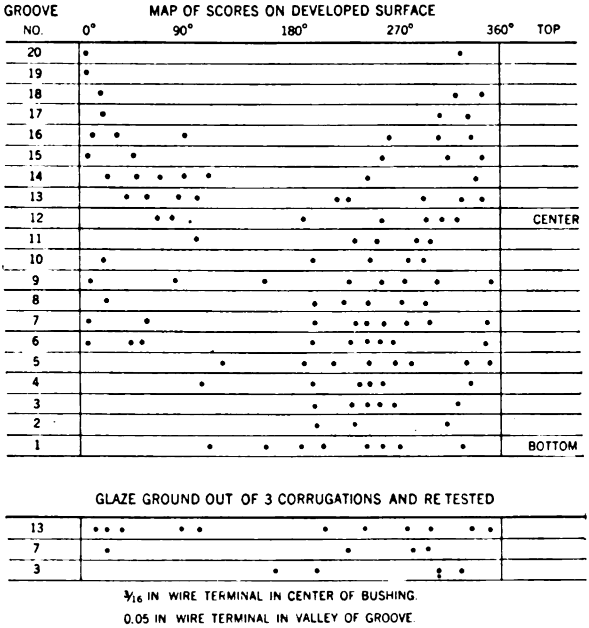


Fig. 34

Map of scored surface of a porcelain bushing to which was applied a voltage gradient test. 120 kv. was applied ten seconds. The small black spots represent the beginning of puncture. The variations in the location of the spots over the surface of the porcelain are presumably due to variation in the quality of the porcelain. The small map below shows three tests on grooves which had the glaze ground off. The electrode was a wire 0.05 in. diameter wrapped around the valley of the corrugation in each of the above tests.

size of the spot and the number of spots was taken as a criterion of damage done. Small spots were given a weight of 0.8 of the average. Large spots were given a weight of 1.2 of the average size of spot. Then the time voltage tests which gave approximately the same number of spots were chosen. The results are plotted in Fig. 35.

It must be confessed that this is a rough method of arriving at the curve and yet it is of fair reliability for this quality of porcelain. It shows that at the higher impressed voltage the time of application must be materially less than when the applied voltages are lower. At something less than 100 kv. it shows that the tests on this particular sample can be applied for an indefinitely long time without starting a fault by concentration of voltage at the electrode.

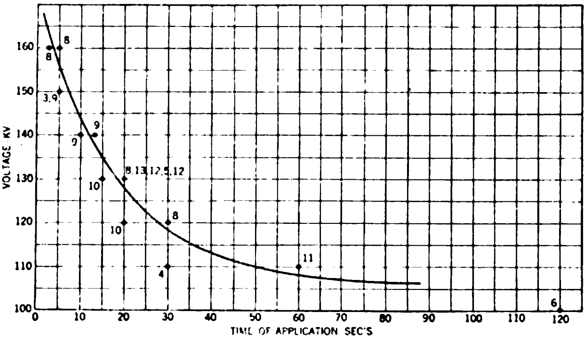


FIG. 35

A rough curve to illustrate the growth of damage to dielectric strength in porcelain bushings at different values of kilovolts applied. At the higher voltages the damage takes place more rapidly than at the lower voltages. This relation gives a rational basis for the proper period of application of test voltage which can be applied without damaging good porcelain.

This is the first step in laying out a rational rule for testing of porcelain. Other tests are being made using wires of larger diameter with corresponding variations in the values of potential gradient in order to determine the law of potential gradient versus damage to the porcelain. The potential gradient is extremely high as compared to the value that causes corona in air, (30 kv. per cm.).

In developing the oscillator and gathering the data herein presented the author takes pleasure in acknowledging the assistance of Messrs. P. E. Hosegood, S. Thomson, and G. F. Gray in the development of the oscillator and of Messrs. R. H. Forney and R. H. Marvin in the experimental studies.

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THE ELECTRIC STRENGTH OF AIR—VI

BY J. B. WHITEHEAD

ABSTRACT OF PAPER

(1) Some of the simpler fundamental experiments on the electrical conductivity of the air are described.

(2) The theory of ionization in gases is outlined in non-technical language.

(3) Townsend's proof that the law of corona forming intensity $E = 32 + \frac{13.4}{\sqrt{d}}$ is in accord with the theory of ionization by collision, is explained.

THEORIES OF GASEOUS CONDUCTION AND OF CORONA FORMATION

AIR, under ordinary conditions an excellent insulator, has also the remarkable property of becoming under certain circumstances a very good conductor. It shares this property with most other gases. Air becomes a conductor when exposed to Röntgen rays, cathode rays, ultra violet light, radio-active substances and other similar influences. In particular it acquires exceptional conductivity in the neighborhood of sparks, brush discharge and the high-voltage corona.

What is the nature of the structure of the air which permits this change of behavior? This is a pertinent question in these pages, since it is this change which places a serious limitation on the use of high voltages. The study of this question has engaged the attention of experimental physicists for many years. It has proved one of the most promising fields for the investigation of, perhaps, the most important of all problems of the physicists, namely, the ultimate nature of matter. Progress in this investigation has been particularly noteworthy within the last fifteen years. Even electrical engineers have contributed in some measure to the results which have been obtained. It is now possible to make a number of definite statements as to the structure of gases, and in particular, to that of air. It is the purpose of this paper to outline the experimental basis upon

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which the modern conception of the structure of the air rests, and several resulting theories of the nature of the high-voltage corona. Effort will be made throughout to keep the description free from technicalities and to avoid as far as possible the introduction of mathematical treatment.

It is with some hesitation that a paper of this character is offered to the Institute. Engineers for the most part have only a passing interest in questions of pure physics. The daily work of most engineers does not involve problems requiring such knowledge. The study of physics, unfortunately, is reduced to an exceedingly small minimum in most of our engineering schools. But in electrical engineering particularly, there seems to be a special reason why the ultimate nature of electrical phenomena should be studied and increasing attention be given to the results of the investigation. Many of the most useful electrical phenomena are not understood, cannot be explained in terms of simpler phenomena, and represent, in many instances, the empirical results of the first discovery. As a consequence of these facts there has fortunately within the past few years been a noticeable recognition of the need of a deeper study of electrical phenomena. Manufacturers have established research laboratories from which results of the highest importance have already been received. National testing and standardizing laboratories have rightly conceived it a proper function to devote more attention to research: Independent workers in increasing numbers are devoting their attention to problems which seem most likely to lead to results of practical value: And lastly may be mentioned an increasing demand that engineers, during their formal training, devote more time to the study of the physical sciences, this demand having been created by wide spread recognition that the deficiency in this respect is a serious limitation.

The writer has also been influenced, in a year of enforced cessation of the experimental work which has been the basis of the foregoing papers of this series, by a desire, to make use of the opportunity to coordinate, as far as possible, the results of all of the papers which have appeared before the Institute on the subject of the electric strength of air, with the theory which we are today asked by the physicists to accept.

The Kinetic Theory of Gases. One of the strongest evidences of the correctness of modern theories of the electric behavior of gases is found in their accord with the kinetic theory of gases. This theory had been established practically beyond attack before the study of the electric properties was begun.

It will be recalled that the kinetic theory assumes that in structure a gas consists ultimately of molecules, which are its smallest indivisible particles. These molecules are in a state of irregular motion or vibration. They collide with each other rebounding to further collisions without definite law. The pressure of a gas in a closed vessel is due to the impact and rebound of the molecules against its sides. The increase in temperature is an increase in the velocity, and hence kinetic energy, of the individual molecules. Compression and expansion of the gas are accompanied by a shorter or longer amplitude of vibration of the molecule between collisions.

The mathematical study of a system of elastic spheres in some such state of vibration as has been described, does not present particular difficulties. The method is based on the principle of averages; that is to say, it does not consider the motion of an individual particle or sphere, but the average motion and average length of path between collision resulting from some presupposed state as to the total amount of energy associated with the entire system of moving particles. Such study has led to many expressions which have been used as a basis for test of the theory. All of the elementary laws of the behavior of gases concerning changes of pressure, volume and temperature, are found to be in accord with the theory, and it may be stated that while this theory can never be subjected to the rigid proof of actual observation, yet nevertheless results of the theory are so universally in accord with known facts as to place the correctness of the theory beyond all question. While a number of instances of this agreement may be mentioned, attention need only be drawn to the fact that particular confirmation is found in the phenomena relating to the specific heat of gases, to the second law of thermodynamics and to the laws of Avogadro, Boyle, and to Van der Walls' extension of the latter.

Of particular interest in the present connection are the results of the kinetic theory which indicate the size, mass, and space separation of the molecules. Our ideas of the diameter of the molecule are derived in several ways; from Boyle's law, and from the coefficients of viscosity, heat conductivity, and diffusion; they all agree very closely. The diameter of the molecule so indicated is about 3×10^{-8} cm. Similarly, the number of molecules per cubic cm. of gas at 0 deg. cent, and 760 mm. pressure is 2.75×10^{-19} power. The velocity of the motion of a molecule between collisions is on the average, in the case of air, about

48,000 cm. per sec., that of the hydrogen molecule being 186,000 cm. per sec. The mass of the molecule of hydrogen, the lightest of the gases is 46×10^{-25} gm. The mass of the molecule of other gases is correspondingly higher, that of oxygen, for example, being 736×10^{-25}. The mean free path, or average length of path of the molecule between collisions under standard conditions is about 10^{-5} cm.

It will be recognized that this conception and these figures are beyond the grasp of our senses. To assist the imagination, Lord Kelvin has stated that if a drop of water were magnified to the size of the earth, its molecules would be about the size of cricket balls. Perhaps it should be stated that the kinetic theory gives no evidence that the actual shape of a molecule is that of a sphere. The figures for the diameter represent the diameter of the range of action of a molecule in its relation to other molecules.

Electrical Conductivity of Air. As already indicated, the results of the kinetic theory and the magnitudes of the quantities given have been used with great advantage by investigators of the electrical properties of gases. We now proceed to a description of some of the methods of investigation and their results.

Air in the free state has electrical conductivity. This conductivity, however, is so small that to observe it directly is extremely difficult. The methods which have been used involve the observation of the rate of leak of static electricity from a charged body by means of the gold leaf electroscope. The results obtained indicate that in the open the current passing between two parallel plates 10 cm. apart and each 100 cm. square, assuming perfect insulation, would be of the order of magnitude 3×10^{-18} amperes. This current moreover is the maximum which may be obtained and does not increase with increase of voltage; also it diminishes greatly if the air is confined in a closed vessel.

The conductivity may be greatly increased by exposing the air to Röntgen rays, ultra violet light, etc., but in these cases also the currents are very small, necessitating the use of sensitive instruments such as the quadrant electrometer. The conductivity so imparted disappears after the exciting cause is removed, although not immediately. It may be removed by straining the air through glass wool, by drawing it through small metal tubes, and by applying an electric field.

These facts suggest that the conductivity is due to something mixed with the gas which also has an electric charge, since it moves out under the action of the electric field. Since the conducting gas as a whole shows no charge, there must also be equal amounts of positive and negative charge. The conclusion is thus reached that the conductivity of the air is due to its having mixed with it electrified particles, some positive and others negative. These particles are called ions, and air or other gas in a conducting state is said to be ionized. This idea is evidently in accord with the kinetic theory of gases, and it is only necessary to add to that theory the assumption that under certain circumstances some of the molecules acquire electric charges, either positive or negative. Leaving aside for later discussion the question how the state of ionization is brought about, it is possible to test the assumption in a number of ways.

With a constant exciting source of conductivity, as for example, a beam of Röntgen rays between two parallel plates forming the electrodes or terminals, we assume that a certain number of ions are formed each second. The volt-ampere characteristic of the air between the plates is as shown in Fig. 1. Under low values of electric intensity, the charged particles are carried to the plates with velocities at first proportional to the intensity. Thus the current is proportional to the voltage, or Ohm's law is obeyed. With increasing voltage the ions are swept out as fast as they are formed, but there can be no more current than there are ions, consequently the curve shows the horizontal portion known as the saturation current. With the further increase of voltage, the air breaks down in the form of corona or spark; we will return to this phase later. One of the interesting results of the theory as substantiated by observation, is the fact that with uniform ionization between the plates, and voltage high enough to produce saturation, the current increases with increasing distance between the plates. The greater the separation the more ions are formed, and, since all are swept out, the greater the current.

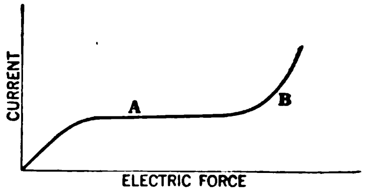

FIG. 1—CONDUCTIVITY OF AIR, SHOWING SATURATION CURRENT (A) AND BREAKDOWN (B)

The ions which are formed by the ionizing agent, being charged molecules or particles, should disappear in three ways; (a) by recombination; (b) by diffusion to the walls of the containing vessel; (c) by being driven to the electrodes under the electric fields. Being in a state of vibration, positive and negative particles will sometimes collide and thus become neutral or no longer ions. Also some of them will drift to the sides of the vessel and will there be neutralized by the induced charges; that is, they give up their charges to the walls. Under the influence of an electric field they will be driven towards the respective electrodes, making collisions and some being neutralized, but finally disappearing as ions.

The current passing through a gas is evidently equal to the difference between the number of new ions formed per second and the number which disappear by recombination and diffusion. This relation can be written in simple mathematical form if the velocity of the ions under the electric force, and the coefficients of diffusion and recombination are known. These quantities have been found by experiment and lead, through the equation for the current, to excellent agreement between the equation based on the theory and the curve as observed experimentally.

The coefficients of recombination may be found by measuring the rate of decay of ionization after removal of source of ionization in air, between plates so far apart that the rate of recombination is far in excess of that of diffusion. Similarly by placing the plates very close together the rate of disappearance due to diffusion may be approximately measured being in these circumstances much greater than that due to recombination.

One of the most important properties of gaseous ions is their motion through the gas under the influence of an electric field. The velocity of this motion has been studied in several ways. One of the best known methods is to measure the electric force required to force the ions against a stream of gas moving with a known velocity. Suppose, in Fig. 2, that air is moving through the space between two concentric tubes with a velocity *V*, and that a beam of Röntgen rays passes through the tubes through small openings as indicated. The ions formed will move down the tube. If voltage is applied between the inner and outer tubes the ions will tend to move to the inner and outer cylinders. If the inner tube is divided at *A*, by moving it from right to left, along the axis, a point will be found where the right hand section will just begin to receive a charge as shown by the instrument *E*. This charge will be due to the ions which started near the point

B; all the other ions will be driven to the left hand section of the inner cylinder. From the value of *V* and of the electric force, and the dimensions of the cylinders, it is possible to determine the velocities of the positive and negative ions.

Another method of measuring the velocity of the negative ions depends on the fact that negative ions escape from a zinc surface illuminated with ultra violet light. The plan of the experiment is shown in Fig. 3. The zinc plate *A* forms one electrode and a wire netting through which ultra violet light may pass, the other. Alternating difference of potential is applied between *A* and *B*. A negative ion starting from *A* will move downward while the negative half wave lasts, but will then start back to the plate *A* again. If, however, *B* is near enough, negative ions will reach it, and there will be a rate of leak from *A* which is observed at *E*. From the distance *A B*, the frequency, and the voltage, the velocity of the negative ions may be readily determined.

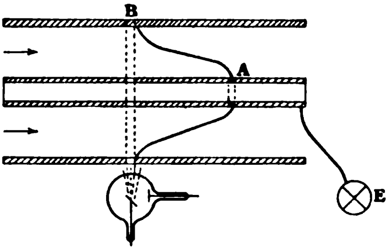

FIG. 2—MEASUREMENT OF VELOCITY OF IONS

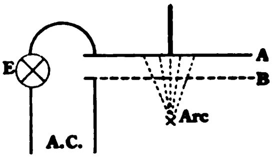

FIG. 3—MEASUREMENT OF VELOCITY OF IONS

From these and other experiments it is shown that the velocity of the positive ion in a field of one volt per cm. and in dry air at atmospheric pressure is 1.36 cm. per sec.; of the negative ion 1.87 cm. per sec.; in moist air the figures are 1.37 and 1.51. In oxygen the figures are about the same as in air; in carbon dioxide 0.76 and 0.81 and in hydrogen 6.7 and 7.9 cm. per sec. It will be observed therefore that in fields of high intensity say 20,000 to 30,000 volts per cm. the ions may attain quite high velocities.

One of the most interesting conclusions reached through the assumption that gaseous conductivity is due to charged ions, is that the charge on an ion is the same for all gases, and that its value is the same as that carried by the atom of hydrogen in the electrolysis of solutions. This conclusion is reached by a consideration of the phenomenon of diffusion of gases, or the process by which two gases, if brought into contact, will slowly mix together. It will be seen that under the kinetic theory of gases this can only take place by motion of the molecules, and it is possible in this way to reach a conclusion as to how rapidly a molecule will move through a gas under the action of a force. In the case of diffusion, this force may be calculated on the kinetic theory from the pressure, temperature, and density of the gas. It is reasonable to suppose that if the molecule is charged, that is, if the gas is ionized under an electric force, the ions will move through the gas in much the same manner as the molecules do in diffusion. This idea leads to a simple relation between the coefficient of diffusion D, the charge on an ion e, the number of molecules N per cu. cm. of gas at pressure P, and the velocity of the ions U under unit electric field, viz. $U/D = \frac{Ne}{P}$. As U, D, N and P can be measured, e may be found, and from experiments on a large number of gases is found to be approximately the same and equal to the charge on the hydrogen ion in electrolysis.

If both positive and negative ions are present in a gas, and in equal numbers, they will move in opposite directions under an electric field, and there will be no resulting motion of the gas. If, however ions of one sign or the other predominate, there will be resultant motion of the gas in the direction of motion of the excess ions. This motion has been frequently observed experimentally, (discharge from points, corona, etc.) and a striking instance of it is described in the third of this series of papers.

The Electron. The first step towards the proof of the independent existence of ions may be said to be due to Crookes, who suggested that the cathode stream, or the bundle of rays which always appears to leave the surface of the negative electrode in a vacuum tube was, in fact, a stream of distinct negatively electrified particles. The evidence of this was found in the shadows cast by the objects placed in the path of the rays, in heat generated at their point of impact, and in their deflection in a magnetic field. It had already been proved by Rowland that a moving electric charge is equivalent in magnetic effect to an electric current. The suggestion of Crookes was that the moving particles were charged molecules.

Following the idea of Crookes, J. J. Thomson in 1897 announced his remarkable experiments showing that the particles in the cathode stream are much smaller than molecules and that their mass is, in fact, only about 1/1800 that of the hydrogen atom in electrolysis, the lightest particle known up to that time. The experiments have been widely described and are well known. In the first of them, by making use of the amount of deflection of the rays in electric and magnetic fields of known intensity the ratio e/m of the charge to the mass of the particles was deduced and also the velocity with which they moved. In subsequent experiments by making use of the fact that, in the formation of water drops by condensation, the first drops form on the negative ions, the value of the charge on the ions was determined and was found to be equal to the charge carried by the hydrogen ion in the electrolysis of solutions. This value taken in conjunction with the ratio e/m leads to the conclusion that the particles in the cathode stream are far lighter than the atom of the lightest known substance.

Numerous experiments have shown that these smallest particles are common to all kinds of matter. The same values are found for different gases and different materials of the electrodes in the vacuum tubes used in the experiments, as well as for the charged particles forming the B-rays of radioactive substances, those forming the discharge from hot bodies, and those shot off from certain substances under the influence of ultra violet light. The newly discovered particles were called by Thomson "corpuscles," but they are now more commonly known as "electrons." They carry invariably a negative electric charge of about 4.7×10^{-10} c.g.s. electrostatic units. So far as is known they have no existence independent of their charge and are in fact generally supposed to be the elementary electric charge. They move with different velocities according to the value of the electric force acting on them. Thomson's values in vacuum tubes were in the neighborhood of 2.6×10^{9} cm. per sec., while those observed in the B-rays are even higher, approaching the velocity of light (3×10^{10} cm. per sec.) The independent existence of individual ions has been shown in beautiful manner by Millikan and by Wilson. The former has been able to study the motions in an electric field of extremely minute oil drops so minute that their rate of fall is very slow. The method involves the microscope and powerful illumination from the side. The oil drops pick up one or more ions and become charged particles. Their rate of fall or rise in the electric field between two parallel plates permits their charge to be calculated. It is found that the increase in charge as the drop picks up more ions, is always a multiple of the charge of the negative ion as found by other means, thus actually isolating the change in charge due to the accession of a single ion.

Wilson, making use of the powerful illumination of small water drops in much the same way, has been able to photograph the path of the positive ion or α particle from radium. Water drops, on the expansion of water vapor, form first around negative ions. If water vapor is subjected at the instant of expansion to the action of radium, the negative ions, formed by the collision of the α particles with the molecules of the water vapor, become centers of condensation, and so form tiny clouds in the general appearance of a thread, along the path of the α particles. If a photograph is taken at the instant of expansion, the paths of the α particles and also of the β particles or electrons are shown with remarkable clearness.

The electrons are supposed to be a common constituent of all matter, and now play a most important role in all modern physical theory. By assuming the presence of varying numbers and arrangements of them in the atoms, and that they are in motion, many phenomena, particularly those of light and radiation, may be explained. In this paper, however, we are only concerned with the part they play in the theory of the conduction of electricity through gases.

Conductivity Due to Electrons. In conductors the electrons are supposed to be very loosely bound to the molecules so that there are large numbers always free, and these conduct the current by motion under the electric force. In a gas, the molecules are in violent motion, and some of their collisions are violent enough to knock off an electron. This electron may attach itself to a neutral molecule forming a negative ion, or it may recombine with a molecule which has already lost an electron forming again a neutral molecule. A molecule which has lost an electron becomes a positive ion. An ion, whether positive or negative may attract to itself other neutral molecules thus forming a charged aggregate of mass larger than the molecule. These aggregates are more commonly found in gases at high pressure, as for example in air at atmospheric pressure. While all these phenomena apparently are common to all gases we will confine our discussion to the air.

In free air then there are always present, on the average, a certain number of free electrons and molecular ions, as the result of collisions and recombinations. It is these ions which impart to air its small conductivity at atmospheric pressure. The number of free ions at atmospheric pressure as deduced from this conductivity is about 1000 per cubic centimeter, whereas the number of molecules per cubic centimeter is 3.5×10^{19}; very few ions therefore are required to show conductivity. This inherent conductivity is so small, however, that it can be observed only with difficulty. Its small value may be appreciated by remembering that air is one of the best insulators known.

Beyond the saturation current of Fig. 1, further increase of voltage results in the break down of the air in the forms of luminous discharge such as the brush, the spark or corona. The theory of ionization has been applied to this region of the curve for the case of parallel plates, and lately to the formation of corona on round wires. The spark and the arc have also been studied but without the striking confirmation found in the two cases mentioned. We will review briefly the case of the passage of current between two parallel plates, and from the information so gained consider the formation of the corona.

THEORIES OF CORONA FORMATION

The sharp turn upwards of the curve of current between parallel plates in Fig. 1 with increasing voltage, marks the region at which sparks begin to pass. This curve may now be completely explained by calculation of the motion of the gaseous ions, if the assumption is made that an ion either positive or negative may in an electric field acquire sufficient velocity to cause, on collision with a molecule, its break up into ions. This assumption, first suggested by J. J. Thomson, has been developed into an extensive theory by J. T. Townsend under the name "ionization by collision." This theory has been widely substantiated by experiment, and is now accepted as the basis upon which all phenomena of electric discharge or conductivity of gases must find their explanation.

While all phenomena of spark discharge are of first importance to the engineer, it is probable that no single one has attracted so much attention of late as the corona formed on round wires. While experimental determination of the voltage at which corona appears on clean wires may be made with a high degree of accuracy, including the effects of temperature, pressure, etc., and while the values of the losses between transmission wires due to corona under different conditions may be predicted quite closely, it remains a fact that none of the phenomena have been satisfactorily explained. The experiments in substantiation of the theory of ionization by collision, have been carried out at low pressures and with parallel plate electrodes, consequently the results have not been directly applicable to phenomena at atmospheric pressure and other forms of electrode.

Townsend has lately attempted to explain the law governing the appearance of corona on round wires. The explanation does not extend to the loss between wires, but it is important to all who are concerned with problems affected by the formation of corona. It is largely the hope of being able to present an outline of this explanation to electrical engineers that has led to the preparation of this paper. It will be necessary, for a proper understanding of the explanation of corona formation now offered to review briefly two or three fundamental experiments.

We have already noted that the negative ion, or electron, is much smaller than the positive ion which is usually of the size of a molecule or larger. The electron moves faster in an electric field, and it generates ions by collision before the positive ion. This may be shown by taking the curve of Fig. 1 with concentric cylinders, first with the inner cylinder (or wire) positive and then negative. In the former case, the upward bend starts at much lower voltage, and therefore on the theory of collision, the negative ion becomes active before the positive.

We will describe two simple experiments as given by Townsend. Let ultra violet light fall on the inner surface of one of two parallel plates; experiment shows that the plate will lose a negative charge. Let n_0 be the number of negative ions s free per second by the light. If the opposite plate is positi charged and if the potential gradient is low, no ions wi produced by collision, the n_0 ions will travel to the p plate, and the current will be independent of the distance between the plates. If, however, the electric intensity is high enough the ions will produce others by collision. Let α be the number of new negative ions produced by a negative ion in going through one centimeter of gas, and n be the total number thus resulting in a layer of thickness, x, measured from the negative plate: then

$$dn = n\,\alpha\,dx$$

$$\log n = \alpha x + \text{const.}$$

$$n = n_0\,\epsilon^{\alpha x}$$

Since when $x = o$, $n = n_0$

Thus for distances $l_1\ l_2$, etc,

$$n_1 = n_0\,\epsilon^{l_1\alpha},\ n_2 = n_0\,\epsilon^{l_2\alpha},\ \text{etc.}$$

$$\therefore\ \frac{n_2}{n_1} = \frac{n_3}{n_2}\,\text{etc.} = \epsilon^{\alpha\,(l_2 - l_1)}$$

the experimental proof consists in showing that the currents which are proportional to n_1, n_2, etc. increase with the distance between the plates in accordance with the exponential law indicated. Also in showing that for the same pressure and potential gradient α is constant for all distances.

Again if n_0 ions are produced by Röntgen rays, in the air between two plates, a distance l apart, in a layer dx, at distance x from the positive plate, a number $\frac{n_0\,dx}{l}$ are generated by the rays. In passing through a distance x, acted on by the electric force X, these produce by collision $\frac{n_0\,dx}{l}\,\epsilon^{\alpha\,x}$; thus the number of negative ions reaching the positive plate is

$$n = \int_0^l \frac{n_0\,\epsilon^{\alpha\,x}\,dx}{l} = \frac{n_0\,(\epsilon^{\alpha\,l} - 1)}{\alpha\,l}$$

the ratio n/n_0 is given by the currents, n_0 being the value when no ions are produced by collisions, *i.e.* the saturation current, and n the value under the electric intensity X. The proof of this formula is found experimentally in the facts that n/n_0 varies with l as indicated, and that α is constant for different values of l.

From experiments of this nature it was found that with constant pressure and increasing electric force, X, α increases to a maximum value. This is in accord with the theory, since α must have a limiting value represented by the total number of collisions it makes with molecules in passing through one centimeter, each collision resulting in the forming of a new ion. Obviously α will also vary with the pressure since, on the kinetic theory, the space separation of molecules increases with decreasing pressure. This is also proved by the experiments. With decreasing pressure and constant electric force, α first increases, since the velocities of the electrons first increase due to the longer time they are acted on between collisions by the electric force. With further decrease in pressure the velocities of the electrons continue to become higher but the number of molecules per centimeter, of path decreases and consequently α decreases again. These facts are stated more generally by Townsend as follows:

"In passing through a centimeter in a gas an ion traverses free paths of various lengths between the collisions. The chance of producing a new ion by collision will depend on the velocity at impact, and this is determined by the force X and the length of the path which is terminated by the collision. The lengths of the free paths are inversely proportional to the pressure, so that if the pressure is increased from p to zp all the free paths will be reduced to $1/z$ of their original value. If the force X remained unaltered, the velocities on collision would be reduced, but if the force is increased to zX the velocities will be restored to their original values and the number of ions arising from a given number of collisions will be the same as before. Since the total number of collisions per centimeter is increased in the same ratio as the pressure, the value of α will be increased to $z\,\alpha$, when X and p become zX and zp respectively Hence the three variables must be connected by an equation of the form

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right)\text{''}$$

The following figures in support of this reasoning are given by Townsend as being typical of a large number of observations:

$p = 2$ mm.	$X = 262$ volts per cm.	$\alpha = 3.7$
$p = 4$ "	$X = 525$ " " "	$\alpha = 7.4$
$p = 8$ "	$X = 1050$ " " "	$\alpha = 14.8$

The strongest substantiation, however, lies in the fact that if α be determined for various values of X and p, and if $\frac{\alpha}{p}$ and $\frac{X}{p}$ be used as coordinates all the points will be found to lie on a smooth curve thus giving the graphic form of the equation

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right)$$

This relation between α, X, and p is the concrete expression of the fundamental assumptions of the theory of ionization by collision. It is the instrument which Townsend uses most freely, and an instance is shown in his explanation of the corona.

The values of α at low pressure (1 mm.) as taken from Townsend's results vary from 10 for $X = 1000$ volts per cm. to 0.7 at 100 volts per cm. One curve shows even lower values for α and X; at 1 mm. pressure and 60 volts per cm. α is 0.1. Thus we would deduce that at 760 mm. under a gradient of 45,000 volts per cm. 76 ions would be produced by one electron in moving through one centimeter. For smaller forces the value of α becomes rapidly smaller, and if we recall that the sparking gradient in air between parallel planes at 760 mm. pressure is about 30,000 volts per cm. the above figures indicate that sparking or other form of breakdown is caused by very few ionizing collisions. It should be noted, however, that all of these figures are taken from experiments at low pressure, 2 mm. to 8 mm., and the values of α are based on measurements of current at values of X/p, which would cause sparking at atmospheric pressure; consequently conclusions as to phenomena outside the range of observation should be taken with caution. At 30,000 volts per cm. and 760 mm. pressure X/p is 39, whereas Townsend's lowest values of X/p for air are between 50 and 60, and as stated, the observations were made at pressures far below 760 mm.

Spark Discharge. Most of the results we have mentioned were obtained under conditions in which negative ions alone are active. But the positive ions also may become ionizing agents. In generating ions by collision, the negative ion at each collision creates a negative and a positive ion. If in the experiment with parallel plates, the separation of the plates is increased, while X and p are kept constant, the current reaching the positive plate increases faster than is indicated by the expression $N_0 \epsilon^{\alpha l}$ which is based on the assumption that negative ions only generate new ions by collision. It may be shown that this increase can be explained on the assumption that positive ions also, if allowed a long enough path and subjected to a great enough force, will also act as ionizing agents. By considering now two quantities α and β, the number of ions generated by the negative and positive ions respectively, in moving one centimeter, the value of the current may be readily calculated, and conclusions may be reached as to how α and β vary with the electric force and the pressure. The results are again in excellent agreement with the theory.

One of the most remarkable and accurate agreements is found in the matter of sparking potential. It will be readily seen that when both positive and negative ions are generating ions by collision, if the distance between the parallel plate electrodes is increased while the electric intensity between them remains constant, more and more ions will be formed and there will come a distance of separation at which the ions will become self perpetuating or the current will continue indefinitely independently of the original supply of ions due to ultra violet light or Röntgen rays, etc. It is an important assumption of Townsend's theory that this condition is equivalent to the passage of a spark. As already stated the values of the electric force and distance between parallel plates for this condition as indicated by the theory are in practically complete agreement with the long established values of the sparking potentials between parallel plates.

Having given this brief description of Townsend's theory and experiments, we proceed to the explanations which have been offered of the formation of corona on round wires.

The Corona. That the surface electric intensity at which corona forms on round wires varies with the diameter of the wire, was clearly shown by Ryan in 1904. In 1911 Alexander Russell using the accurate figures obtained by the author and given in the first paper of this series showed that the law connecting the corona forming surface intensity and diameter of wire, at constant temperature and pressure, may be expressed by the simple relation

$$E = 32 + \frac{13.4}{\sqrt{d}}$$

Shortly afterward Peck, exploring the influence of temperature and pressure, announced the following important modification of the above expression in which δ is the "density factor" referred to 760 mm. and 25 deg. as unity.

(The writer's values of the constants have been retained).

$$E = \delta\left(32 + \frac{13.4}{\sqrt{\delta d}}\right).$$

The first attempt at an explanation of this comparatively simple expression appears to have been that of Russell. Noting that the corona sends out electromagnetic waves, Russell assumes that these waves are the cause of the ionization, and that they are set up by collisions between positive and negative ions resulting in neutral systems. The energy of the original separate charges is liberated as magnetic waves. We may with advantage quote him directly:

"Let us suppose that n is the concentration of the positive and negative ions in the corona. By the molecular theory of gases we know that the number of collisions per second between pairs of ions will equal αn^2, where α is a constant.' The total number of collisions per second per unit length of the wire will be $2\pi a\ (\alpha n^2)$, and we may assume that violent ionization begins when this attains a certain constant value. Hence, so far as the size of the inner wire is concerned, the critical value of n varies inversely as $\sqrt{a}$. If we suppose that the value of the electric stress R at the surface of the corona is constant, and remember that the concentration n of the ions in the corona is proportional to the potential gradient across it, we get

$$R_{max} = R + \frac{B}{\sqrt{a}} \text{"}$$

It is evident that this point of view does not include the idea of ionization by collision. It appears to present several difficulties. For example it does not suggest how the original supply of positive and negative ions is furnished, also it assumes that the kinetic theory of gases holds within the corona, and that the potential gradient throughout the corona is the same as at the surface of wire. The assumption that electromagnetic waves can cause ionization is of course justified, (Röntgen rays, etc.) but the other assumptions require proof. In spite of the attraction of the simple explanation of the inverse square root of the diameter the explanation does not appear very satisfying.

Bergen Davis in his paper before the Institute entitled "Theory of Corona" frankly bases his theory on the ideas of Townsend and in fact starts from the expression $n = n_0\, \epsilon^{\alpha x}$ which is explained earlier in this paper. It will be recalled that n_0 is assumed as the number of negative ions crossing unit area of a plane in a gas, and that under ionization by collision in which α is the number of new ions produced by one ion in moving through one centimer, n is the number of negative ions crossing unit area of a plane or reaching an electrode at distance x.

Davis' suggestion then is that under the alternating potential of a high-voltage wire, the negative ions, always present in the air, move inward on one-half wave and in so doing create new ions. On the next half wave they move out, some recombining, but on the whole more remaining than on the foregoing half wave. These in moving inward and thus reaching a more intense field, create more ions, the whole process being cumulative, until finally the number n reaching the conductor attains a critical value necessary for the appearance of the corona. In the development, the plane of n_0 is a cylinder around the wire, of such radius b that the electric intensity X_0, uniform over all this surface, has the value of the least potential gradient at which ionization by collision takes place. The radius b of the cylinder across which n_0 ions pass when corona forms, thus depends on the radius a on the wire, on the voltage E, and the distance R to the opposite conductor.

In the brief description of Townsend's theory above, the values of α were studied for uniform fields of force and α was found to be constant as long as the electric intensity and pressure were constant. Obviously the electric intensity is not constant in the neighborhood of a round wire, and it is a feature of Davis' discussion that he writes the above relation between n, n_0 and α in the form $\frac{n}{n_0} = \epsilon^{\int_a^b \alpha\, dx}$, noting that since α is a function of X it must be a function of x the distance from the center of the wire. He then introduces an expression for α in terms of x as developed in an earlier paper of his own and supported by experiments by Bishop giving indications of the amount of energy required to ionize a molecule. A discussion of the form of the expression of α and its integration, and the subsequent handling of the equations need not be attempted here as the original papers may be consulted. It will suffice to state that after several radical assumptions Davis reaches expressions between radius of wire and critical intensity which agree closely with the experimental results of Peek and those of the writer.

The discussion contains so many assumptions which cannot be tested that it leaves the reader in considerable doubt as to its accuracy. Two conspicuous difficulties may be mentioned. First, no account is taken of the ionizing action of the positive ions, although it is practically certain that in all forms of spark discharge they play an important part. Second, the agreement between the theory and the results of experiment depends on the author's assumption that the minimum ionizing intensity for air at atmospheric pressure has the value 26,600 volts per cm. All observers now agree that the value of this intensity is between 30,000 and 32,000 volts per cm.

Townsend's Theory of Corona Formation. Until quite recently, practically all of the tests of the accuracy of the theory of ionization by collision have been based on experiments at low gas pressure. The greater part of the experimental work of Townsend and his co-workers has been done at pressures below 8 mm. of mercury. Owing to the longer free-paths of the gas molecules at low pressures it is easier to trace the changes in conductivity due to the presence of ions, and consequently the law and resulting theory as to the nature of the phenomena are more readily studied and developed. It is for this reason that the theory of ionization by collision, as developed by Townsend, and as very briefly outlined above, does not lend itself readily to the explanation of arc, spark and other types of discharge at atmospheric pressure. Townsend has, however, applied the theory to the phenomena of spark discharge at low pressures and has shown a remarkable agreement between theory and experimental observation. In explaining the corona at atmospheric pressure he makes use of this agreement since he considers the corona a particular form of spark discharge.

In brief outline, Townsend's proof that the corona may be explained by the theory of ionization by collision consists in three steps:

(1) The laws of sparking at low pressures between parallel plates are in accord with the theory of ionization by collision;

(2) The fundamental relation of the theory, connecting pressure, electric force and the number of ions generated by a single ion in moving one centimeter $\left(\alpha = pf\left(\frac{X}{p}\right)\right)$, when applied to a concentric wire and outer cylinder, leads to a simple relation between radius of wire, electric force and pressure which is in agreement with the results of experiment.

(3) The values of electric force necessary to form corona are in agreement with the forces which may be calculated from the laws of sparking between plates.

(1) All three of these steps are necessary for complete identification of corona as a case of ionization by collision, but our

interest lies chiefly in the third. We will, however, first indicate briefly the agreement mentioned in the second step, omitting entirely discussion of the first, since the nature of the proof has already been suggested and further discussion would lead beyond the scope of this paper.

(2) The relation mentioned as the second step of the proof is that when corona is formed on wires of different radii at different pressures the product $a \times p$ is a function of $a \times X$ where p, a and X are pressure, radius, and critical surface intensity. In other words, if a and p are varied so that their product is constant than aX will also be constant. This relation follows simply by comparing the number of new ions generated by a single ion in moving through corresponding paths in two cases of concentric wire and cylinder, one in which the radii and pressure are a, A and p, and the other in which they are ka, kA and p/k. The proof need not be given here. Townsend quotes Watson's results as follows, in support of the correctness of this reasoning; the values of p and a were chosen so that the product ap has the same value.

p	a	X	ap	AX
760	0.1	75	76	7.5
560	0.136	55	76	7.5
360	0.211	34	76	7.2
760	0.2	61	152	12.2
560	0.272]	44.5	152	12.5
360	0.422]	28.5	152	12
760	0.5	46.5	380	23.2
560	0.68	35	380	23.7
360	1.055]	22	380	23.2

It will be noticed that the product AX is constant for ap constant. In a recent paper Townsend and Edmunds have reported observations of the corona forming intensity on five sizes of wire (0.006 to 0.476 cm.) in two sizes of cylinder (1.98 and 7.45 cm.) over a range of pressure one mm. to 760 mm. These results offer a much wider range for comparison than those of Watson. A large number of values of aX were obtained for each of 18 values of ap. The agreement in each case was very good.

(3) The simplicity of the form of the expression connecting critical corona intensity with the radius of the wire at atmospheric pressure has always suggested that it should have a

simple explanation. Townsend has been the first to offer the explanation. As often happens, it is simple enough to cause surprise that it has not been seen before. Further it depends on the theory of ionization only insofar as does the phenomenon of spark discharge. Explain sparking on any other theory and the law of corona formation is explained on the same theory. It should be noted, however, that there are in reality no other theories of sparking which have been developed to an extent comparable to that of ionization by collision.

Assuming that the electric intensity or force at the outer boundary of the corona is 30 kilovolts per centimeter, the minimum sparking intensity for air, the average intensity in the corona is $\frac{X_1 + 30}{2}$ X_1, being the intensity at the surface of the wire, at which corona is formed. Thus on the assumption that corona is a form of spark discharge this average intensity should be equal to that required to cause a spark to pass between two parallel plates separated by a distance $S = c - a$, c being the radius of the outer boundary of the corona, and a that of the wire. Now the law for sparking potentials between plates separated by small distances has long been known and is $V = 30S + 1.35$, V being in kilovolts. Consequently by the above assumption

$$\frac{X_1 + 30}{2} = 30 + \frac{1.35}{c - a}$$

The radius of the corona c may be expressed in terms of X, by noting that forces at points outside the wire are inversely as their distances from the center. Thus X_1, being force at distance a, and 30 that at distance c, we have $c = \frac{a X_1}{30}$ substituting:

$$\frac{X_1 + 30}{2} = 30 + \frac{1.35}{a \left\{ \frac{X_1}{30} - 1 \right\}}$$

or

$$X_1 = 30 + \frac{9}{\sqrt{a}}$$

which agrees very closely indeed with the author's results as given in the first and second papers of this series, and also with those of Peek and Watson.

Although, as stated above, it is not necessary to invoke the theory of ionization to deduce the above relation at atmospheric pressure from the laws of sparking, the same cannot be said when the influence of pressure is to be included. The aid given us by the theory at this point is perhaps one of the most satisfying evidences of its correctness. We have already indicated that the theory shows that for the formation of corona Xa is a function of pa. Applying this to the above relation between a and X, and expressing p in atmospheres we have:

$$X_1 a = f\,(pa)$$

at $p = 1$,
$$X_1 = 30 + \frac{9}{\sqrt{a}}$$

or
$$X_1\,a = 30\,a + \frac{9\,a}{a}$$

$$\therefore \mathrm{X}_1\,a = 30\,pa + \frac{9pa}{\sqrt{pa}}$$

or
$$X_1 = p\left(30 + \frac{9}{\sqrt{pa}}\right)$$

this relationship was first shown experimentally by Peek who verified it over a wide range.

While the above satisfactory explanations of corona formation, and the experimental results confirming them, are all based on the assumption and use of continuous potentials, it has been noted several times that corona forming intensities have practically the same values for both continuous and the maximum values of alternating voltages. Although the exact identity of the values needs further proof, it is certain that, at low frequencies at least, practically the same law as to corona formation is obeyed by both alternating and continuous voltages. It has already been shown in these papers that the frequency, up to values of 2500 cycles, has little effect. The results of Ryan, however, indicate a pronounced effect at extremely high frequencies.

While, therefore we now have a very satisfactory explanation of the first appearance of corona there still remains the greater problem of the power loss above the corona forming point. The results of Mershon and Peek show, over a wide range, the values of the loss which may be expected on transmission lines in the open. Experiments are now needed on clean smooth wires, and a study of the results in the light of the theory of ionization by collision. When this is done and the results compared with the interesting empirical law proposed by Peek, the electric properties of the air at atmospheric pressure so far as they are of importance to engineers will be fairly well understood.

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THE RELUCTANCE OF SOME IRREGULAR MAGNETIC FIELDS

BY JOHN F. H. DOUGLAS

Abstract of Paper

The development of the idea of magnetic reluctance is sketched, and the mathematical and experimental methods of determining it are first discussed. On the theoretical side it is the theory of complex quantities which leads to numerical results.

The electric field of an electric generator is next analyzed and made to depend approximately upon the reluctance of two-dimensional magnetic fields. This study indicates as preferable the one shown in Fig. 6 at the left.

The reluctance of these various magnetic fields is determined by experiments made on sheets of high resistance metal cut in suitable forms, and by mathematical computation. These results are put into charts and formulas convenient for the use of those interested in electrical design. The results of the tests are proved to be more accurate than most of those already published. In particular, present leakage flux calculations are most in error.

Of more general interest are the plates of the shape of the magnetic lines of force in the various parts of electrical machinery. In particular, Figs. 42 to 48 include some new results. The flux lines in the corners of transformers and induction motors are there shown, and the exact solution to the much discussed sine-wave alternator problem is there given.

The paper is divided into (I) Introduction (II) Historical Development, (III) Description of Experiments, (IV) Accuracy of results, (V) Conclusions. There are two appendices giving some mathematical details, for reference purposes.

I. Introduction

If we apply a difference of magnetic potential between two portions of the surface bounding a region of space, a certain amount of magnetic induction will be developed. If no induction crosses the remainder of the surface, we have a region which is a tube of induction, carrying a definite amount of flux and consuming a definite amount of magnetic potential or mangetomotive force. All such magnetic fields possess a definite amount of reluctance, R, which is the ratio of the applied magnetomotive force, M, to the resulting flux, ϕ, thus,

$$R = M/\phi \tag{1}$$

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If there is no magnetic saturation present this reluctance is a constant. Only fields in media without saturation are considered in the following paper quantitatively. A few flux distributions in iron are, however, considered qualitatively.

The reciprocal of reluctance is called permeance or magnetic conductance. It is denoted by P; thus,

$$P = 1/R = \phi/M \tag{2}$$

If the lines of flux flow are everywhere parallel and the equipotential sections are everywhere the same, the magnetic field can be said to be regular. Such a field has a reluctance which can be readily expressed in terms of its dimensions. Thus,

$$R = L/\mu A \tag{3}$$

where L is the length of the magnetic flux path, A the area of its cross-section, and μ the permeability of the medium.

The above equation can not be used for an irregular magnetic field, except for an infinitesimal portion of a tube of induction, where infinitesimal values of L and A may be taken. Recourse must be had, therefore, to the fundamental definition of reluctance in equation (**1**) by considering the mutual relations between M and ϕ.

In this paper attention will be limited to some irregular two-dimensional magnetic fields; that is, to fields in which the flux lines are all parallel to some plane surface. The results, however, will be extended to apply to certain three-dimensional fields, by making approximate assumptions.

Owing to the fact that there is no magnetic insulator known, the magnetic fields around dynamo electric machinery is very irregular. There is fringing of flux in the air-gap, and leakage flux between the poles and around the slots. As a consequence designers have to use various correction factors, which even yet are more or less empirical. A study of the field of typical electrical machines was made in search of forms of magnetic circuit which needed study. In addition, on the mathematical side, various cases were canvassed systematically. Beginning with those simple shapes which led to simple integrals, study was made of all possible forms up to those which involved integrals more difficult than the elliptic integrals of the first and second kind. Of all these cases those promising any use were selected for study. It is in the hope that some of the cases which are worked out here might be of use, that the experiments and the mathematical work were carried out. Some of the results may be of use in analogous electrical problems.

The exact significance of equation (**1**) can best be obtained by reviewing briefly the historical development of the subject, tracing out the gradual unfolding of the conceptions involved. This will form the first natural division of the subject.

The various experimental methods, which have been used will be described, and discussed in the next section of the paper. Before describing a set of experiments made with high resistance metal strips, an analysis of the magnetic field surrounding an electrical machine will be made.

The simplifying assumptions, made in picking out certain two-dimensional fields as applying to what is in reality a three dimensional problem are sufficiently serious to warrant discussion. Before passing on, therefore, to the conclusions, the accuracy of the results will be compared with that of the present methods.

The detailed mathematical treatment of the problem of the reluctance of irregular magnetic fields, is not included in this paper, because of its complexity and too special interest. Nevertheless the writer went over the ground, both mathematically, and experimentally, and found both methods needful for securing the best results. Those interested in this side of the subject, can consult the references given in the historical section of this paper. Those who prefer to use an analytical formula to a curve of permeance, can consult an appendix to this paper where the mathematical results are given. Another reason for their inclusion is that, while the figures were drawn carefully, greater accuracy might in some cases be desirable.

II. Historical Development

Equation (**1**) is sometimes called Ohm's law for the magnetic circuit, from its similarity to the law of the same name in the electric circuit. This similarity is made the basis of the experiments described in this paper. Although simple in its final formulation, the law was discovered at a comparatively late date, because the ideas implied were of gradual growth. The existence of a potential function, the solenoidal character of magnetic force, the identity between electromagnetism and permanent magnetism, the existence of magnetic induction within iron, the idea of a closed magnetic circuit, were all needed for the final formulation of Ohm's law for the magnetic circuit.

The existence of potential, as a function whose space derivatives give the components of the fields of force, is due to La Place[1] who used it with reference to the attraction of gravitation. The name itself is due to Green[2] who proposed it in his prize essay published in 1828. La Place showed that gravitational potential satisfies the equation

$$\frac{d^2V}{dx^2} + \frac{d^2V}{dy^2} + \frac{d^2V}{dz^2} = 0 \qquad (4)$$

which is known by his name. This equation followed from the law of the inverse square of the distance discovered by Newton.[3] The suitability of such a function in the case of magnetism must have been apparent, because magnetic attraction was already recognized as a case of central forces. In 1785 Coulomb[4] demonstrated that the inverse square law was true for magnetism. The application of potential to magnetic theory followed at once.

In 1813 Poisson[5] called attention to a limitation to La Place's equation showing that it did not apply to the interior of the attracting body. In 1827 he derived the correct equation for the space within an attracting mass.[6] Owing to this difference, for a time the magnetic field inside a magnet was thought of as entirely different from that outside of the same.

In July 1820 Oersted[7] discovered electromagnetism, and a very short time after that Ampere[8] showed the equivalence of an electric circuit with a magnetic shell. Thus, the existence of a magnetic potential was proved for all points of the magnetic field except those within the magnetizing coil. The variation of magnetic potential within the substance of iron, however, was still unknown. These same experiments of Ampere's furnished us also with the idea of magnetic potential as related to an electric current. The unit of magnetic potential, however, came later.

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[1] Memoires de l'Academie Royal de Paris, 1782. Mechanique Celeste Book. 3, Chap. 2.

[2] Collected Papers p. 25.

[3] Principia, (1687) Book 3, Prop. 1-7. See also Thomson and Tait, "Natural Philosophy" Part 2, p. 9.

[4] Memoires de l'Academie Royal de Paris; 1785 p. 583; 1788, pp. 587 and 603.

[5] Nouveau Bul. Soc. Philomatique Vol. 3, pp. 388-392.

[6] Memoires de l'Academie de Paris Vol. 6, July 10, 1827.

[7] Schweigger's Journal Vol. 29, p. 273.

[8] Ann. de Chemie et Physik. 1820. Gilbert's Annalen, Vol. 67, (1821).

The concept of electric current as the universal cause of magnetism, even in permanent magnets was the last step in the development of the theory of magnetic potential.[9] In magnets revolving electrons within the atom constitute the source of magnetic potential.

The idea of a magnetic flux is also of gradual growth. At first, magnetic effects were considered as being exerted at a distance and manifested only when iron filings, a compass needle, or other magnetic body was present. However the labors of Gauss and Weber with their charts of magnetic fields served to make the idea of fields of force more tangible. In 1813 Gauss[10] proved that the surface integral of magnetic force over any closed surface is proportional to the amount of attracting matter within it. This he proved directly from the law of inverse squares. The constancy of this integral could not help but suggest the idea of a flux or flow of force, constant in amount, from one magnet pole to another. This so-called solenoidal character of magnetic flux was, however, really implied in La Place's equation.

If H_x, H_y, and H_z are the three components of the magnetic field parallel to the three co-ordinate axes, and if the field is solenoidal,

$$\frac{dH_x}{dx} + \frac{dH_y}{dy} + \frac{d\,H_z}{dz} = 0 \qquad (5)$$

That electromagnetism was solenoidal followed at once from Ampere's discovery that a current was equivalent to a magnetic shell.

In 1831 when Faraday[11] discovered magnetic induction, he was inevitably lead by the idea of cutting lines of force to the conception of the physical reality to be ascribed to them. His experiments in 1851[12] confirmed the solenoidal character of magnetism within the substance of the magnet itself. The concept of tubes of force and of induction followed at once.

The belief in a magnetic circuit of flux was of gradual acceptance. At first the identity of the tubes of induction outside the magnet with those inside was not clear. The term Magnetic Circuit was first used in 1833 by Ritchie,[13] and the term closed magnetic circuit in 1853 by Dub[14] and De la Rive.[15] The connection between magnetic force and induction in iron and the distinction between them, outside magnetic substances, was all that was then needed before Ohm's law for the magnetic circuit could be formulated. These were supplied by the discoverer.

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[9] Werner v. Siemens, Wiedeman's Annalen, Vol. 24 (1885), p. 94; Larmor, " Aether and Matter," (1904), p. 108.

[10] Werke, Band 5, p. 9.

[11] Experimental Researches, First Series, Vol. 1.

[12] *Ibid*, Vol. 3, Sects. 3077 and 3109.

The earlier theory of induction in iron took into account two distinct actions going on at once. First, there was a magnetic field inside the iron but due to outside influences. Second, there was a field due to the polarization of the iron itself. Although this conception is helpful, it delayed the formulation of Ohm's law for the magnetic circuit. It was on the basis of this theory that the early determinations of the quality of iron was made. In 1854 Kirchoff[16] calculated the susceptibility of iron from some of Weber's experiments with an iron ellipsoid. In January 1873 Stoletow[17] first used the ring method of testing for determining the quality of iron.

We owe the statement of Ohm's law for the magnetic circuit to Rowland,[18] who not only determined the experimental relation between magnetic force and induction within iron, but also distinguished between the two. He originated the conception of magnetic force as a localized magnetomotive force. That is, magnetic field intensity was the gradient of magnetomotive force, rather than the flux density which would be set up in air, were the magnetic substance removed. The name of permeability as the ratio of magnetic induction developed in iron to that produced in other bodies is due to Lord Kelvin,[19] who attributed the idea of magnetic conductivity to Faraday. However, this point of view can be traced back as far as 1821, when Cumming[20] measured crudely what corresponded to magnetic conductivity rather than susceptibility. This was a rather close approach to the idea underlying Ohm's law for the magnetic circuit. Permeability as the permeance of a unit cube is of course due to Rowland.

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[13] *Phil. Mag.* Series 3, Vol. 3, p. 122.

[14] Poggendorf's Annalen, Vol. 90, p. 436.

[15] Treatise on Electricity, Walker's Translation, Vol. 1, p. 293.

[16] Crelle's Journal, Vol. 48, p. 374.

[17] *Phil. Mag.*, Series 4, Vol. 45, p. 40.

[18] *Phil. Mag.*, Series 4, Vol. 46, p. 140, (Aug. 1873).

[19] Papers on Electricity and Magnetism, p. 484, (1872).

[20] Camb. Phil. Trans., Apr. 2, 1821.

Rowland also proposed, in his article, the ampere-turn as the unit of magnetic potential difference. In opposition to this Bosanquet[21] later proposed as a unit ($10/4\pi$) of an ampere-turn. He also coined the term "magnetomotive force." This unit of Bosanquet's has persisted in spite of the priority of Rowland, and in spite of the return to the confusion between field intensity in air and induction in air, apparently because of the great influence of Maxwell. Maxwell[22] spoke of the intensity of a magnetic field as defined by the result of excavating a cavity in the iron of a particular shape. This "mouse and cheese" theory has always been a hindrance to electrical engineers, and manufacturing companies have always used magnetization curves in the form developed by Rowland.[23] Recent Text books[24] still disagree as to the issue thus raised.

The term reluctance for magnetic resistance is due to Heaviside,[25] while the term permeance is due to S. P. Thomson.[26] The use of reluctance and Ohm's law for the magnetic circuit of dynamos was first brought to the attention of engineers by Hopkinson,[27] who however introduced a modification by using curves of induction plotted against field intensity, or *B-H* curves. The suitability of Ohm's law for parallel as well as series magnetic circuits was pointed out first by Kapp.[28]

The beginning of the theory of the reluctance of two-dimensional magnetic fields, was in the mathematical theory of goedetic lines of various kinds. This was next applied to the flow of electric currents in two dimensions and finally extended to magnetic problems. Maxwell attributes the application to the electric current to Prof. W. R. Smith,[29] and develops it himself in Chap. XII of his "Treatise." The following points are worthy of notice. (1) His treatment involves the theory of the conjugate functions of a complex variable. (2) Although this is the usual basis for the theory, his conclusions are independent of this method of treatment. (3) Part of this theory is essential to an understanding of the graphical and the experimental methods. (4) His exposition is confusing to those who do not care to go into the mathematical method deeply. (5) A brief outline of this theory is necessary.

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[21] *Phil. Mag.*, Series 5, Vol. 15, p. 205, (Mar. 1883).

[22] Electricity and Magnetism, Vol. 2, Sect. 398, p. 24, 3rd Ed.

[23] Ayrton and Perry, Jour. Soc. Teleg. Eng. & Elec., 1886, p. 518.

[24] Karapetoff, "Magnetic Circuit," 1st Ed. p. 12 and p. 266. Pender, "Principles of Electrical Engineering," Chap. II.

[25] *Electrician*, (London), Vol. 21, (1888), p. 27.

[26] Dynamo Electric Machinery, 4th Ed. (1892), p. 186.

[27] Phil. Trans. Royal Soc., 1886 Part 1, p. 331.

[28] Jour. Soc. Teleg. Eng. & Electr., 1886, p. 530.

[29] Proc. R. S. Edin., 1869-70, p. 79. See also Treatise on Electricity and Magnetism, 3rd Ed., p. 185.

The reluctance of an irregular two dimensional magnetic field, such as "*OAPB*" in Fig. 1, is

$$R = R'\nu/t \tag{6}$$

where ν is the reluctivity or reciprocal of the permeability μ, t is the thickness, and R' is a constant which depends only upon the shape of the field. If we always work with a thickness

$$t = \nu \tag{7}$$

of the field, we see that R' is the reluctance of such a slice and is independent of the material. R' may be called the geometric reluctance of the field.[30]

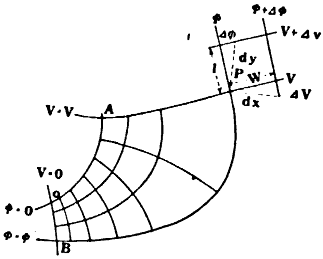

FIG. 1

Each line of flux may be characterized by a number called the flux function. This is defined as the amount of flux passing between this line of flux and an arbitrary point or zero of reference, and within a thickness of the field equal to its reluctivity. The flux function at a point is that belonging to the flux line passing through that point.

The geometric reluctance R' is expressible through the flux and potential functions. Thus in Fig. 1, the geometric reluctance of *OAPB* is,

$$R'_{\text{OAPB}} = (V_p - V_o)/(\phi_p - \phi_o) \tag{8}$$

The total reluctance of a slice of any thickness can be obtained by combining equations (6) and (8). A study of the reluctance of two-dimensional irregular magnetic fields is nothing else than the study of the graphical and analytical relations between the potential and the flux functions.

Let us consider the field in Fig. 1 as divided by lines of force at equal increments of the flux function $\Delta\phi$, and also by equipotential lines at equal intervals $\triangle V$ which are equal to $\triangle\phi$. Let us consider that the field is divided also by parallel planes into laminae of a thickness $t = \nu$. The field is divided thus into cells each of which has a reluctance of unity, and all the angles of which are right angles. Moreover if the intervals $\triangle\phi$ and $\triangle V$ are sufficiently small, the curvature of the sides of the cells can be neglected. That each cell is a square, is easily seen from equation (**3**). Putting $A = t \times w$, the thickness being t and the width of the cell being w, we get,

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[30] Karapetoff, "Magnetic Circuit," Chap. 5, p. 93.

$$R = \frac{(\nu)\ (l)}{(t)\ (w)} = 1.$$

Since t is equal to ν, the length of any cell l must be equal to its width w. The dimensions l and w are, however, shown in only one of the squares of Fig. 1. The fact that the flux and potential lines form what may be termed curvilinear squares, is made the basis of the graphical method of determining the reluctance of an irregular magnetic field.

If we consider in Fig. 1 an infinitesimal square formed by two lines of flux, ϕ and $\phi + \triangle\phi$, and by the two equipotential lines V and $V + \triangle V$, we can see from the geometry of the figure that,

$$\frac{dV}{dy} = \frac{d\phi}{dx}; \quad -\frac{dV}{dx} = \frac{d\phi}{dy} \tag{9}$$

Functions satisfying these relations are called conjugate functions. By differentiating the first of the preceding equations with regard to x and the second with regard to y, we obtain, after combining,

$$\frac{d^2\phi}{dx^2} + \frac{d^2\phi}{dy^2} = 0 \tag{10}$$

in other words the flux function, as well as the potential function, satisfies La Place's equation in a two-dimensional magnetic field.

The mathematical similarity between the flux and potential functions, suggests the possibility of transposing the roles of the potential and flux functions. It must be plain that, since the flux and potential lines form squares rather than rectangles, there can be no reason why one set of mutually orthogonal lines need be chosen as flux lines rather than the other. Thus for every two-dimensional magnetic field, there is an exactly similar field in which the roles of the two sets of lines is completely interchanged.

Inasmuch as it is possible experimentally to trace out only one set of these lines, it is very convenient by transposing the field to obtain the other. Very considerable use was made of this principle in making the experiments described in this paper.

The mathematical methods used in treating the problem involves the use of complex numbers such as $x+\sqrt{-1}\,y$ or $x+jy$; and more particularly the use of functions of these complex variables as representing the equations of the lines of force and the equipotential lines. The idea of giving a geometrical signification to the square root of a negative number is due to Argand[31] who suggested in 1806 that $X+jY$ or $X+\sqrt{-1}\,Y$ could be represented by a point with the co-ordinates X and Y.

The importance of the theory of complex numbers lies in the fact that, if we equate,

$$W = \phi + jV = F(X + jY) = F(Z) \qquad \textbf{(11)}$$

we obtain two functions of X and Y, that is ϕ and V, which are conjugate to each other.[32] Thus ϕ and V are related to each other as a two-dimensional flux function and potential function.

The properties of rational algebraic and trigonometric functions of a complex variable were familiar to Cauchy and Euler but precise ideas of what constituted functionality were lacking until Rieman.[33] In 1799 Gauss[34] proved that all functions of a complex number were themselves complex numbers. Thus graphically, for every point (X, Y) in the Z plane there is a corresponding one (ϕ, V) in the W plane. Equation **(11)** can be thought of as transforming any figure in the W plane to a corresponding figure in the Z plane.

In 1822 Gauss[35] proved that the transformations effected by equations of the type of equation **(11)** were conformal; *i.e.* the angular relations were preserved and the corresponding infinitesimal parts of the two diagrams were similar. For instance in the equation,

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[31] Essai sur une manière de represente les quantities imaginaires dans les constructions geometrique.

[32] Rieman, Gessamelte Werke, p. 5, see also Webster, Dynamics of Particles and of Rigid, Elastic and Fluid Bodies, p. 522.

[33] Chrystal, Algebra 4th Ed. 1898, Vol. 1, p. 253.

[34] Gessamelte Werke, Vol. 3, p. 1.

[35] *ibid*, Vol. 4, p. 192.

$$t = \xi + j\eta = F(X + jY) \tag{12}$$

we may regard the function $F(\quad)$ as transforming an irregular conductor in the (X, Y) plane into another conductor in the (ξ, η) plane. These conductors are equivalent since the equipotential and flux lines in one conductor are all changed conformally in the new conductor; that is, without changing the shape of the enclosed cells of reluctance. In particular in equation (**11**), the lines in the Z plane formed by the lines $\phi = 0, 1, 2,$ etc. and $V = 0, 1, 2,$ etc. are small curved squares, and any rectangular conductor bounded by flux and equipotential lines is converted into an equivalent irregular conductor. If one tries a few simple functions of $(X + jY)$, and plots the curves of constant ϕ and V, he can quickly convince himself of the truth of the above statements. The importance of this principle to the theory of the reluctance of irregular magnetic fields, is that it furnishes a means of converting irregular into rectangular conductors, of which the reluctance is known.

In 1825 Gauss[36] showed that every conformal change could be represented by equation (**12**) provided only that the proper functions be found. This was equivalent to proving that every irregular conductor could be converted by this equation into an equivalent rectangular conductor. While it would be more convenient to make this conversion directly, it is generally found necessary to make the conversion in two steps through an intermediate irregular conductor equivalent to both. A conductor whose only boundary is an infinite straight line is found to be a most convenient intermediate form.

As a simple example of the use of the above method, let us take the function,

$$\phi + jV = (X + jY)^2; \; \phi = X^2 - Y^2 \; ; \; V = 2\,X\,Y.$$

the lines of flux and equipotential are mutually orthogonal hyperbolas. We can use this function therefore to find the reluctance of any figure bounded by these lines, such as that in Fig. 2. Thus

$$R = \frac{V_a - V_b}{\phi_p - \phi_o} = \frac{2\,X_a\,Y_a - 2\,X_b\,Y_b}{(X_p^2 - Y_p^2) - (X_o^2 - Y_o^2)}$$

$$= \frac{2 \cdot 5 \cdot 5 - 2 \cdot 5 \cdot (-5)}{(3^2 - 0^2) - (0^2 - 0^2)} = \frac{100}{9} = 11\,\frac{1}{9}$$

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[36] Schumachers Astr. Abh. 1825, Ges. Werke, Vol. 4, pp. 189-216.

From the point of view of equivalent conductors, the above equation may be said to convert the irregular conductor in Fig. 2 into the rectangle $V = 50$, $V = -50, \phi = 0$, and $\phi = 9$. The method illustrated by this problem has its limitations; for the proper function needed to suit a particular boundary is not always known.

The transformation of a polygonal area conformally into a half plane has been known since 1867, and is due to Christoffel[37] and Schwartz.[38] This is equivalent to converting a polygonal conductor into its equivalent conductor having a straight line boundary. We are then able to find its reluctance easily by converting it a second time by the same theorem into a rectangle.

Let it be desired to convert the polygonal conductor shown in Fig. 3 into its equivalent conductor consisting of an infinite half plane with a straight line boundary. Let $Z = (X + jY)$ be the co-ordinates of any point in the polygonal conductor, and let $t = \xi + j\eta$ be the two rectangular co-ordinates of the corresponding point in the equivalent conductor with the straight line boundary. Then Schwartz's and Christoffel's theorem states that,

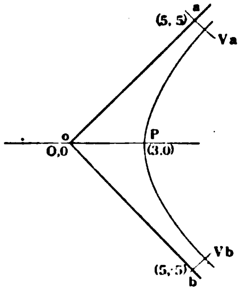

FIG. 2

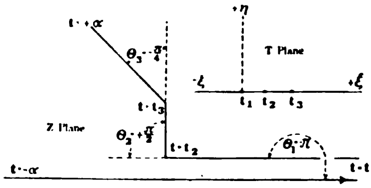

FIG. 3—DIAGRAM ILLUSTRATING SCHWARTZ'S THEOREM

$$Z = \int C(t-t_1)^{\frac{\theta_1}{\pi}} \cdot (t-t_2)^{\frac{\theta_2}{\pi}} \cdots (t-t_n)^{\frac{\theta_n}{\pi}} dt \qquad \textbf{(13)}$$

where θ_1, θ_2, etc. are the angles shown in the figure, being plus when measured toward the right and minus when measured to the left. The constants t_1, t_2, etc. at the corners of the boundary are the co-ordinates of the corresponding points in the straight line boundary of the t plane. Three of these constants are arbitrary, and the remainder are determined by the geometry of the polygonal conductor. The constant C determines merely the size and orientation of the equivalent conductor as a whole. There is of course another equation similar to equation (**13**) which transforms the conductor in the half t plane into a rectangular conductor in the W plane, whose co-ordinates are ϕ and V.

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[37] Annali di Matematica, Vol. 1, (1867), p. 89.

[38] Crelle, Vol. 70 (1869), p. 105. See Also, J. J. Thomson, " Recent Advances in Electrictiy and Magnetism" p. 208.

When the equations of the lines of force and equipotential surfaces are desired, it is necessary to keep the signs and arguments of the various terms in equation (**13**) perfectly correct. When, however, the reluctance or resistance only of the irregular field is desired, without regard to the shape of the flux and equipotential lines, a simpler method may be used. In this case we integrate equation (**13**) without regard to argument, using only the moduli of the various terms, from one corner of the figure to another. In other words, the equation is integrated from t_1 to t_2, t_2 to t_3 etc. This method makes graphical integration possible.

The first use of Schwartz' and Christoffel's theorem for an electrical problem was made by Kirchoff[39] who used it to determine the capacity of plate condensers. The first suggestion of using the method in magnetic phenomena is due to F. W. Carter,[40] who adapted Kirchoff's and Thomson's results to the pole-tip fringing in an electric machine. J. J. Thomson[41] used the method in his book " Recent Advances" to find the capacity of the guard-ring electrometer and F. W. Carter[42] applied the result with some improvements to slot and air-duct fringing. The results are limited theoretically to the case of infinitely broad teeth, and infinitely deep slots. C. H. Lees[43] has determined the effect of a sudden change in the width of a conductor upon its resistance. He also found the effect of a narrow saw-cut on its resistance.[44] The writer has applied the method generally to check his experimental results. Since these computations are not included, it should be stated that the agreement was in all cases very close.

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[39] Monatsberichte der Akad. der Wiss. zu Berlin, Vol. 15, p. 144. See also J. J. Thomson, " Recent Advances" Chap. 3, Section 238.

[40] Inst. Elec. Eng. Jour. Vol. 29 (1900), pp. 925-933.

[41] Chap. 3, Sect. 241, p. 227; and Sect. 243, p. 233.

[42] *Electrical World and Engineer*, Vol. 38 (1901), p. 884. See also Inst. Civil Eng. Proc., Vol. 187 (1912), p. 311.

[43] *Phil. Mag.*, 5th Series, Vol. 16 (1908), pp. 734-739.

[44] Phys. Soc. Proc., Vol. 23 (Aug. 1911), pp. 361-366.

An application of this theorem to hydrodynamical problem has been made by Mitchell[45] and Love[46]. There are a few other more or less complicated cases where Schwartz' theorem has been applied, but these will not be quoted because they seem to be mostly of academic interest.

For irregular conductors bounded by circular arcs, reference may be made to Forsythe Theory of Functions 2nd Ed., Art. 271, p. 644. For the flux and potential problems in thin curved sheets, see Darboux, "Theorie General des Surfaces."[47]

The reluctance or resistance of irregular fields in three dimensions does not in general admit of solution. Indeed, there is not such thing as a flux function, except in a few cases. One of these is when the bounding surfaces and all the flux and potential lines are in surfaces of revolution. These cases are frequently met with in electrostatic problems, and therefore offer scope for future work along these lines. The following references are given to aid further study.[48]

Closely allied to the analytical method of conjugate functions is a graphical method due to L. F. Richardson[49] and to Dr. Th. Lehman.[50] It is quite fully developed by these authors for a two-dimensional field. It depends essentially upon the fact that the small square cells of such a field can be quite accurately drawn by the judgment of the eye, and also upon the fact that it is easy to adjust them correctly by the use of a pair of dividers. In this way various irregular fields can be drawn, and by counting the number of squares in series and in parallel, the reluctance of the field can be obtained. Mr. Richardson points out how the method may be used in the case of irregular fields bounded by surfaces of revolution, and also to the case of bodies made of a material showing saturation. Use was made of this method in drawing Fig. 26.

A very striking experimental method of determining the shape of the lines of force in a magnetic field is due to Hele-Shaw, Powell, and Hay[51] using the property that a viscous fluid in steady motion flows according to the same laws as an electric current. In order to render the stream lines visible, they injected thin lines of coloring matter. They controlled the permeability of the medium, by varying the thickness of the layer of fluid. They determined in this way the field resulting when cylinders, rings, toothed and shuttle armatures, and other variously shaped bodies are introduced into a magnetic field. They checked in this manner the theoretical work done by Carter.[52] They were followed by Dr. W. M. Thornton,[53] who used the method for determining the flux distribution in the armature cores of electrical machines. These plates are reproduced in a paper by Hansen before the A. I. E. E.[54] An application of the same method for determining the electrostatic fields in a three-phase cable has been made by Thornton and Williams.[55]

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[45] Phil. Trans. Royal Soc., 1890 part A, p. 389.

[46] Proc. Camb. Phil. Soc., Vol. 7 (1891), p. 175.

[47] Vol. 1, Book 2, Chap. 4, pp. 170, 176-180.

[48] Stokes. "On the Steady Motion of Incompressible Fluids" Camb. Phil. Trans. Vol. 7, 1842: Math. and Phys. Papers, Vol. 1, p. 15. Sampson. "On Stokes' Current Function" Phil. Trans. 1891, Part A.

[49] *Phil. Mag.*, Series 6, Vol. 15, Feb. 1908, p. 237.

[50] E. T. Z. Vol. 30, (1909) pp. 995-1019. Lumiere Electrique, Vol. 8, No. 43, p. 403.

In order to use the above method to determine the actual reluctance of an irregular field of force, measurements were made of the pressure of the liquid supply, the quantity of flow, and the coefficient of viscosity.

The most useful experimental method of determining the reluctance of irregular magnetic fields, is to make use of the similarity of the electric and the magnetic circuits, and measure the resistance of the corresponding irregular electric circuit.

Kirchoff[56] was the first to propose determining the equipotential lines and resistances of an irregular two-dimensional electric current field, by the use of a specially cut sheet of metal and specially fastened electrodes. Application of the method to other cases was made by G. Carey Foster and Sir Oliver Lodge[57] in 1875, who gave a good bibliography of this part of the subject. Gaugain[58] modified this method by using liquid conductors such as Mercury, Zinc Sulphate, and Copper Sulphate. W. G. Adams[59] developed Kirchoff's method, making suititable for three dimensions, and using liquid instead of solid conductors.

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[51] *Electrician* (London), Vol. 54, Nov. 25, 1904, p. 213. Phil. Trans. Royal Soc. Vol. 195, 1900 Part A, p.'303-327.

[52] *Electrical World and Engineer, Loc. Cit.*

[53] Jour. Inst. Elec. Eng., Vol. 37 (Feb. 26, 1906), p. 125.

[54] A. I. E. E. TRANS. Vol. 28, June 30, 1909, pp. 993-1001.

[55] *Engineering*, Vol. 88, Aug. 27, 1909, p. 297.

[56] Poggendorf's Annalen, Vol. 64 (1845), p. 497.

[57] Proc. Phys. Soc. of London, Vol. 1, pp. 113-193.

[58] Ann. de Chemie et de Physik, No. 3, Vol. 64, 1862, p. 200.

[59] Proc. Royal Soc. 1875, Vol. 23, p. 280.

The use of an electrical experiment upon thin sheets of an electrical conductor, for determining the reluctance of the corresponding magnetic fields was proposed by F. W. Carter[60] in 1901. He himself, however, used only the mathematical method. He also proposed the use of the conjugate character of the flux and potential functions to determine the shape of the lines of force. Since a millivoltmeter can only be used to trace equipotential surfaces, if we desire to trace lines of flow, we must contrive to interchange the two sets of lines. Mr. Carter proposed cutting a metal strip, to the shape of the desired irregular magnetic field, but to solder the electrodes to those parts of the boundary which were flux lines. The remaining or desired equipotential portions of the boundary were to be left free. In this way, an interchange of the roles of flux and potential functions is secured upon the boundary, and consequently throughout the rest of the strip also.

The suggestions of Mr. Carter were first carried out by Mr. C. H. Smoot[61], who used the method to check experimentally the reluctance of a case solved theoretically by Mr. Carter. He applied the method, also, to get the flux distribution in the air gap of an alternator. Both suggestions of Mr. Carter were used by the writer in the tests described in this paper.

An application of the similarity of the electric current field to the electro-static field, has been made in 1913 by Fortescue and Farnsworth[62], who used a three-dimensional electrical model of various irregular electrostatic fields. Recently R. Forster[63] has developed a method of determining the electrostatic field which he applied to a three-phase cable. He used a conducting liquid, and to avoid polarization, inverted the functions of the galvanometer and battery circuit of a Wheatstone bridge. The method seems to have points of similarity to one of those used by G. Carey-Foster and Sir Oliver Lodge.[64]

III. Description of Experiments

In order to determine the reluctance of various irregular magnetic fields, use was made of the similarity of the electric and the magnetic circuits, and of the conjugate character of the flux and potential lines. The resistances of various irregular sheets of metal were measured upon an apparatus shown in Fig. 4, and the equipotential lines were also traced out. This was done to determine the permeance of the similar magnetic field, and the shape of the lines of force.

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[60] *Electrical World and Engineer, loc. cit.*

[61] Jour. Western Soc. Eng. Vol. of 1905, p. 500.

[62] A. I. E. E. Trans., Vol. 32, Part I (1913), p. 893.

[63] *Archiv fur Elektrotechnik*, Vol. 2, 1913, No. 5, pp. 175-180.

[64] Proc. Phys Soc. of London. *Loc. Cit.*

Measurement of the resistance consisted in setting the stylus attached to the terminals of the millivoltmeter alternately on the two points between which the resistance was desired, and adjusting the terminal on the slide wire for a null reading. This was easily done, as the millivoltmeter had a zero center, and both a ten and a hundred millivolt scale. Readings were taken of the two ammeters and of the settings upon the slide wire.

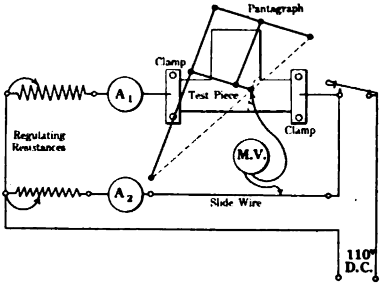

FIG. 4—DIAGRAM OF CONNECTIONS USED IN EXPERIMENTS

The main current and the current in the slide wire were maintained constant to suit frequent calibration tests. Since the absolute resistance was not desired, but only the geometric resistance, calibration of the meters was not made. The calibration of the slide wire was effected checking it against a regular or rectangular sample cut from the same sheet as the irregular sample, and ruled into exact squares. In this way identical thickness was secured between the irregular sample and the sample for calibration. The current in the slide wire was adjusted so that the drop in twenty centimeters was twenty millivolts. This current was held rigorously constant. The main current was adjusted carefully at each calibration so that the drop in one square of the calibration sample was equal to that of approximately twenty centimeters upon the slide wire. In any case the exact drop in the calibration sample K was noted. In other words a drop of K centimeters on the slide wire was equivalent to one unit of geometric resistance or reluctance both in the regular calibration sample, and the irregular sample for testing. Thus to find the resistance between two points 1 and 2 at which the slide wire settings were V_1 and V_2, we divide the difference of the settings by K.

Direct deflection of the millivoltmeter was not used except, when under special circumstances, a range beyond that of the slide wire was required. For this reason a drop of twenty millivolts per twenty centimeters of slide wire was chosen so as to make extrapolation easy.

In most of the problems investigated it was desired to determine the shape of the lines of flux, while the millivoltmeter could only trace equipotential lines. Hence the roles of the flux and equi-potential lines was transposed, by fastening the electrodes to only those parts of the boundary which, in the magnetic problem, are flux lines. In this way the millivoltmeter can be used to trace the flux lines. The resistance, as measured in this way, is really the geometric conductance or permeance of the problem which it is desired to study. Thus we have for computing the permeance the equation

$$P = (V_1 - V_2)/K \tag{14}$$

In tracing out the equipotential lines upon the test sample, the slide upon the slide wire was set upon a suitable point and the stylus which touched the plate was moved about so as to find points for which the millivoltmeter deflection was null. The stylus was carried by a pantagraph and thus the lines of force were drawn at once. The slide wire settings were usually varied four centimeters at a time; so that each strip, marked off in this way, could be divided graphically into five cells of square shape. However this was not invariably followed; and always at any singular point, such as at a corner, an extra line was traced. While experiments were in progress, the use of a pantagraph for tracing equipotential surfaces was described by Fortescue and Farnsworth in their A. I. E. E. paper mentioned above.

The metal selected for testing was an alloy made by the Driver-Harris Co. by the name of "Therlo." The sheets were approximately 10 mils thick. ($\frac{1}{4}$ mm.) The specific resistance was approximately 40 michrohms per centimeter cube. This metal was selected because of its high specific resistance, small temperature coefficient, and low thermo-electric power when used with copper.

The first tests were made to test for thermal effects which were found to be negligible. The samples were clamped between heavy copper terminals, projections having been left upon those edges of the sample which it was desired to maintain at a constant potential.

The next tests were made to determine the effect of contact resistance drop between the test sample and the copper clamps. The drop was found to be considerable and steps were taken to reduce it. First the copper terminals were cleaned with emery cloth, and then partly amalgamated. The drop was reduced in this way considerably, so that regular tests were begun. In order not to include the contact resistance drop the potential was read upon the therlo sheet, but very close to the copper electrodes. To facilitate this work, a fine line was ruled upon the metal sheet on which the potential was desired, The copper electrodes were then clamped very near and parallel to this line.

It was noted, in cases where the clamps were so placed that the current entered the metal sheet non-uniformly, that the potential along the desired equipotential line varied, because of a varying contact resistance drop. Upon comparing the results with those calculated from the mathematical theory, certain discrepancies were discovered. Search was made for constant errors, and found in excessive contact resistance, and too infrequent calibration samples. Also, in certain cases, thickness measurements were made rather than the equality of thickness between calibration and test samples secured. In such a small thickness as 10 mils, this was of necessity somewhat in error. The figures shown in this paper were mostly taken during this first series of tests. It is believed, however, that the shape of the lines of force are substantially accurate, even if the spacing between them is only approximate.

In the second series of tests a rectangle was cut from every irregular shaped template after it was tested; and this rectangle was used for calibration. Owing to the large number of tests made it did not seem desirable to solder the electrodes directly to the therlo sheet in order to secure a low contact resistance, because, in each sample tested, the electrode was cut to a smaller size several times. The following compromise proved to be very satisfactory. Thin strips of copper about five mils thick were soldered to the test sample accurately adjacent to the line on which the potential was desired. This combination was clamped between the heavy electrodes. The double thickness of therlo and copper was easily cut. Not only was the contact drop greatly reduced in this way, but the highly conducting copper strip served to redistribute the current before it entered the therlo test sample. Even when the current entered the therlo sheet more in some places than in others, the voltage setting along the desired equipotential line hardly varied at all. This was in marked contrast to the first series of tests. In this way not only was the difficulty of contact resistance overcome, but in such a manner that the work was rapidly clamped, measured, unclamped, cut to a new size, and occasionally resoldered.

A few irregular test pieces were measured and found to give results in complete agreement with the mathematical theory. It was believed then that the constant error was eliminated. In one of the last series of tests, it became necessary to solder several sheets of therlo together, in order to obtain a template of sufficient size. Owing to warping and the presence of oxide the seam had to be very wide, and the sample was, therefore, heterogeneous. As a consequence some constant error in these tests is to be expected. Fig. 25 shows the arrangement in this case, together with the method adopted in laying out an irregular template and trimming it to size.

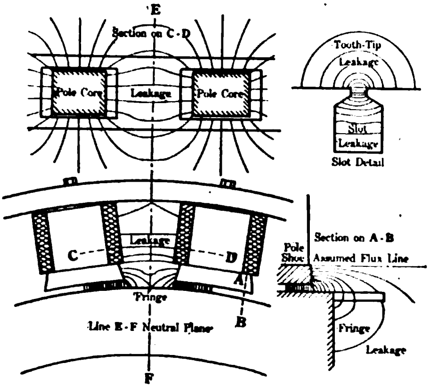

FIG. 5—FLUX DISTRIBUTION AROUND AN ELECTRIC MACHINE

Figure (5) shows roughly the general character of the lines of force around a multipolar electric machine. It is apparent that the lines of force are not parallel to any one plane except perhaps in the air-gap. Nevertheless the sketch suggests various irregular two dimensional fields, which are at least approximations to the actual field. In Fig. 6 is shown the various subdivisions of the field of an electric machine, which result from imagining the lines of force guided by certain surfaces. At the right is shown the best assumptions as made at present, while at the left is shown another method, which will be shown in a later paragraph to be more accurate. It will be noted that the assumptions made in the figure at the left reduce the various sections of the field to two-dimensional flux distributions, suitable for treatment by the methods outlined. Another point of interest is that the figure at the right shows some obvious sources of error; namely, in two places two kinds of flux are supposed to occupy the same space at the same time, and also the field is the more cramped of the two. In the experimental work the shapes of the irregular magnetic fields shown in Fig. 6 at the left were systematically taken up and studied. In addition a few extra topics of some interest suggested themselves as the work progressed and were investigated.

The effect of the slots and teeth upon the value of the air-gap reluctance, has been partially investigated by F. W. Carter and reported in the *Electrical World*.[65] He assumed infinitely deep slots, and infinitely wide teeth, and neglected the effect of the notches cut to receive the wedges. These factors are reported on here.

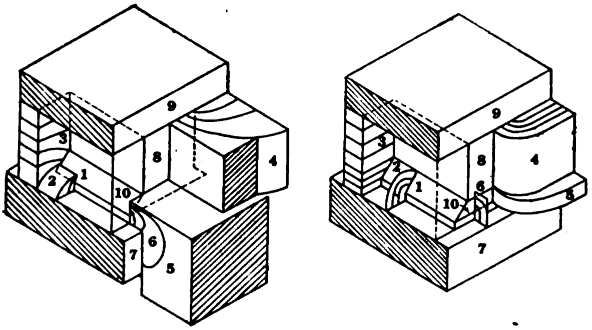

Fig. 6—Subdivisions of the Field of an Electric Machine

1—Pole tip fringe
2—Pole tip leakage fringe
3—Pole side leakage
4—Pole flank leakage
5—Pole shoe flank leakage
6—Pole shoe flank fringe
7—Armature core
8—Pole core
9—Pole yoke
10—Pole shoe and poletip

In Figs. 7 and 8 is shown the flux distribution in the air-gap of a slotted armature. The sample of sheet metal for testing was cut in the form shown by the letters *a*, *b*, *c*, *d*, *e*, *f*, the electrode being soldered to the strip at the lines *ab* and *de*. When the current was passed through the strip, the curved lines of force were traced out by the pantagraph as shown. The measured resistance gave the permeance of the flux from the tooth ends and that in the tooth fringe combined. Since this combined permeance depends upon the tooth width, $2x$, we usually desire to find the excess or fringe of this permeance. That is, the fringe permeance is the amount that the total permeances in excess of that which might be expected to pass from the ends of the teeth, under the assumption that the lines of force were all radial. In Fig. 7 the permeance of the fringe is calculated from experimental values by the formula,

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[65] *Loc. cit.*

$$P_f = \frac{V_e - V_a}{K} - \frac{2x}{g} \tag{15}$$

Here $(V_e - V_a)/K$ is the total measured permeance, and $2x/g$ is the apparent permeance directly between the teeth and the pole surface.

In Figs. 7 and 8, g represents the air-gap, S the slot width,

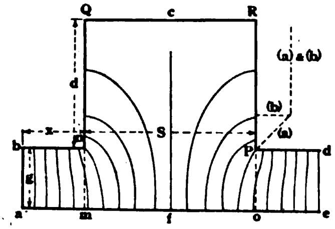

FIG. 7—TOOTH FRINGE FLUX FOR SMALL AIR GAP

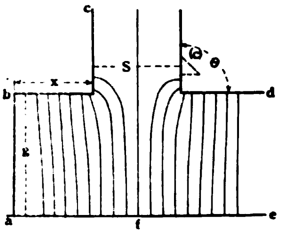

FIG. 8—TOOTH FRINGE FLUX FOR LARGE AIR GAP

D the slot depth, θ the angle between the tooth side and end. In general the symbols used will be clear by a reference to the figure. The dotted lines labeled a, b and c represent three shapes of notches cut to receive the slot wedges. These notches in the test pieces were cut to a depth of 20 per cent of the slot width on each side.

Some of the data together with computations are shown in Table 1; the results are plotted in Fig. 9. In addition the effect of the depth of the slot, and the inclination of the tooth tip were studied and these results plotted in Figs. 9 and 10.

It is to be noted, that the effect of the depth of the slots is negligbile until the depth is less than the width. Also, it is apparent that the presence of a notch has little effect unless the tooth tip forms an angle less than 90 deg. The data for the other cases studied were worked up in exactly the same way, and will not be included in this paper.

TABLE 1.
DATA AND COMPUTATIONS FOR DETERMINING FRINGE PERMEANCE FROM TEETH.

Calibration:

Meter A_1 read 12.0 amperes, Meter A_2 read 32 millivolts.
Drop in one square of calibration sample equaled 19.95 centimeters drop on slide wire.
Thickness of sample 9.6 mils.

Test Data and Computations.

(1) Effect of shape of armature slot, when $l' > S$ and $x = 1$.

Shape	S	g	V_a	V_e	$\frac{V_e - V_a}{19.95}$	$\frac{2x}{g}$	P_f	$\frac{S}{g}$
(a)	10.0	5.0	9.9	44.4	1.71	0.400	1.31	2.0
(b)	10.0	5.0	9.7	45.5	1.79	0.4	1.39	2
(c)	10.0	5.0	9.7	45.7	1.80	0.4	1.40	2
(d)	10.0	5.0	9.6	45.7	1.805	0.4	1.405	2
(a)	7.0	1.0	12.2	105.8	4.69	2.0	2.69	7.0
(b)	7.0	1.0	12.6	110.5	4.90	2.0	2.90	7
(c)	7.0	1.0	13.1	111.3	4.93	2.0	2.92	7
(d)	7.0	1.0	13.8	112.2	4.93	2.0	2.93	7

(2) Effect of depth of armature slot, when $S/g = 8$, $S = 10$, and $x = 1$.

D	g	V_a	V_e	$\frac{V_e - V_a}{19.95}$	$\frac{2x}{g}$	P_f	$\frac{D}{S}$
15.0	1.25	12.5	103.2	4.535	1.60	2.935	1.50
5.0	1.25	12.1	105.2	4.650	1.60	3.050	0.50
2.5	1.25	12.3	113.7	5.070	1.60	3.470	0.25

Note: Shapes *a*, *b* and *c* refer to the shapes of the tooth-tip shown in Figs. 7 and 8. Shape *d* is rectangular pole tips without any notch cut for the slot wedge.

The curve in Fig. 9 for infinitely narrow teeth, and in Fig. 10 for various depths of slots, were obtained mathematically and and not experimentally. It is interesting to note that whether the teeth are infinitely wide or infinitely narrow the fringe permeance is nearly the same. Experimental results for moderately wide teeth agreed more closely to the curve for infinitely wide teeth.

The practical effect of the slots is to increase the air-gap reluctance, or to decrease its permeance. We may think of the effective area of the flux as decreased, and the ratio of this decrease as the air-gap factor K_a.

The effective area is very readily computed from the curves of permeance in Figs. 9 and 10, by multiplying the permeance

P_f by the air gap "g" to get the amount to be added to the width of each tooth for fringing.[66] Analytically the tooth fringe Δt is

$$\Delta t = P_f \times g \tag{16}$$

On the other hand we may think of the average length of the lines of force in the air-gap as increased in the ratio K_a.

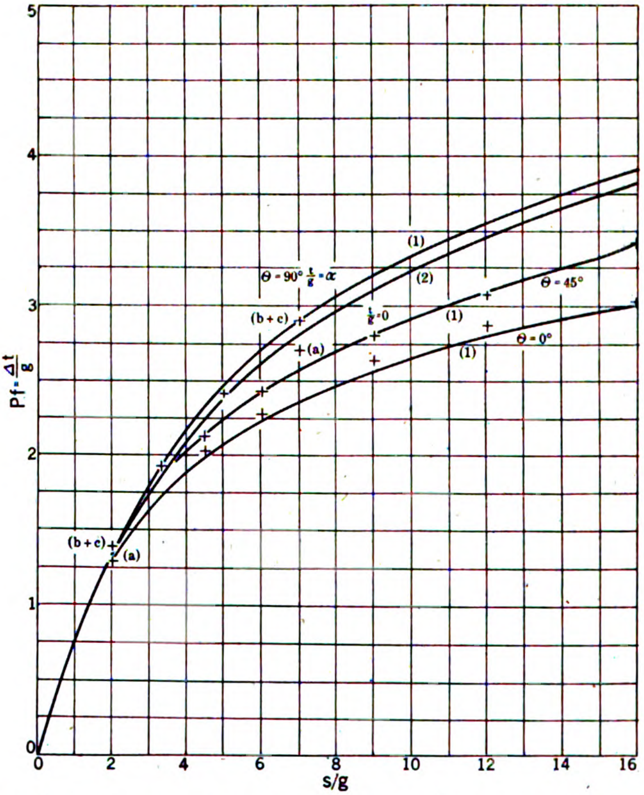

FIG. 9—FRINGE PERMEANCE FROM SIDES OF TEETH TO ARMATURE (DEEP SLOTS)

1. Infinitely wide teeth. 2. Infinitely narrow teeth.

This point of view is perhaps the most helpful when the air-gap is long, for two reasons. In the first place with a long air-gap the ratio of S/g is small and Figs. 9 and 10 are inaccurate. In the second place, a theoretical investigation showed that the width of the tooth had an important effect in this case while the size of the air-gap was unimportant. The results of this investigation are shown in Fig. 11. The excess length to be added to the air-gap is obtained by taking the reluctance R from the curve and multiplying it by the tooth pitch, λ. Analytically the excess air-gap with Δa is,

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[66] For example see Karapetoff "Magnetic Circuit" Chap. 5, p. 93.

$$\Delta a = R_e \lambda \tag{17}$$

That the width of the teeth has an important effect upon the air-gap reluctance for long air-gaps, is seen by comparing with the approximate curve also shown in Fig. 11. This approximate curve was calculated from the formula for Figure 9, curve 2, for a small ratio of S/g.

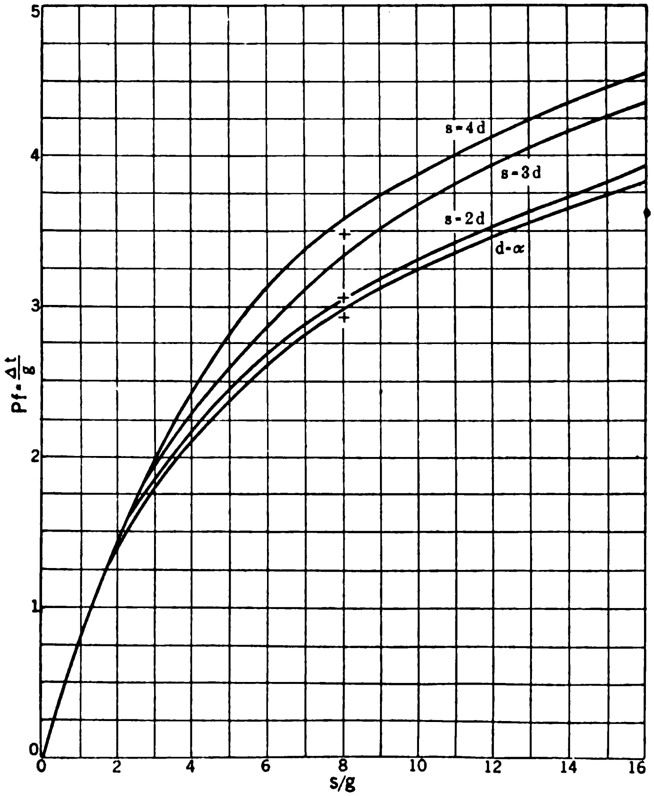

Fig. 10—Fringe Permeance from Sides of Teeth to Armature, for T/G = 0

The case of the air-gap of an induction motor is one that proved too difficult for the writer's power of analysis. However, it is a case that might well be studied from the experimental side. It has been partly solved by, F. W. Carter,[67] in a footnote of an article on Magnetic Centering of Electrical Machinery.

The various approximate formulas for air-gap factor are now of little interest, a short bibliography, however is given.[68]

Because of desired economy of space a detailed description of each experiment will not be given. In each case the shape of the template cut for testing can be seen by referring to the figure giving the shape of the lines of force. The portion outlined by the letters *a*, *b*, *c*, *d*, *e*, *f* in each case gives the shape of the test

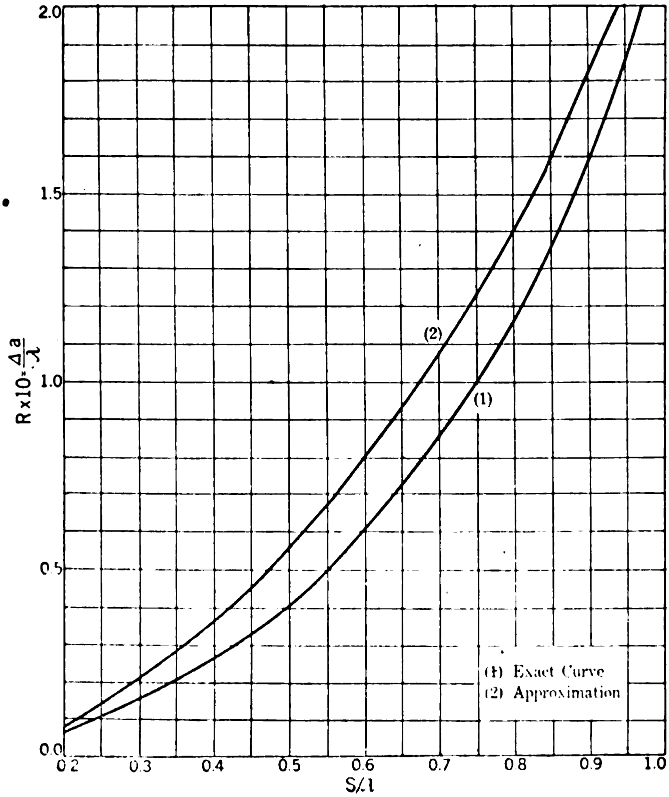

FIG. 11—EXCESS RELUCTANCE OF AIR-GAP FOR EXTRA LONG AIR-GAPS

piece, the electrodes being soldered to the lines *ab* and *de*. In each case data was taken in a form similar to Table 1, and the permeance calculated in the same manner. In all cases the curves of permeance were calculated by means of the mathematical method as well as the experimental method, and in all cases the results were found to agree very closely. Any special features differing from the above are specially mentioned.

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[67] Proc. Inst. Civil. Eng. Vol. 187, (1912), p. 311.

[68] Guilbert, Ind. Electrique, Vol. 9, (1900), pp. 377-379. Muller, E. T. Z., Vol. 1906, Vol. 27, p. 1103. Wall, Inst. Elec. Eng. Jour., Vol. 40, pp. 550-568. Baillie, Electrician (London), Vol. 62, (1909), p. 494. Rezelman, Lumiere Electrique, Vol. 11, (1910), p. 202.

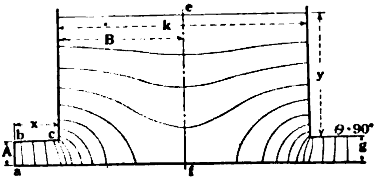

Fig. 12—Shape of Pole-Tip Fringing Flux

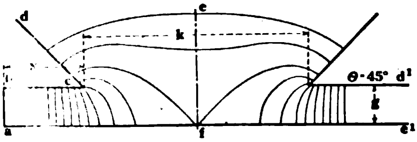

Fig. 13—Shape of Pole-Tip Fringing Flux

The magnetic field in the interpolar regions of a dynamo is shown in Figs. 12, 13, 14, and 15. The flux which leaves the pole *b c d* is composed of two parts. The one which passes to the armature directly between *a* and *f* is the useful flux, while the rest between *f* and *e* passes directly from pole to pole and is leakage. Just as the useful flux may be divided into the air-gap flux, and the pole tip fringe, so the leakage flux may be divided into the pole side leakage (calculated) as if passing directly from one pole to the other) and the remainder which may be called the pole tip leakage flux. The pole tip fringe may be calculated from the experimental data by the formula,

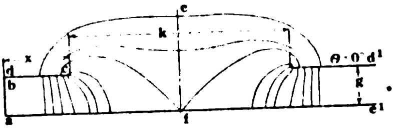

Fig. 14—Shape of Pole-tip Fringing Flux

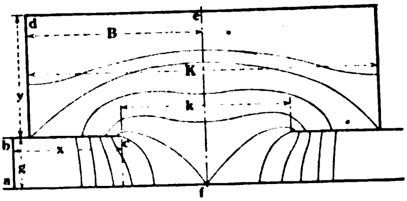

Fig. 15—Shape of Pole-tip Fringing Flux, Projecting Pole-Tips

$$P_f = (V_f - V_a)/K - (x/A) \tag{18}$$

The pole tip leakage fringe may likewise be calculated by the formula,

$$P_{lf} = (V_e - V_f)/K - (y/B) \tag{19}$$

Here V_a, V_f, and V_e are the slide wire readings at the points a, f and e as shown in the figures, and K is the calibration constant.

The values of the pole-tip fringe permeance are plotted in Figs. 16 and 17 and that of the pole-tip leakage permeance in Fig. 18. It is interesting to note that the curves for pole-tip fringe, are similar in shape to those for tooth-tip fringe as in Fig. 9 except for a constant difference of 0.88: this is easily proved by the mathematical method given above. An approximate curve used frequently at present is that of Hawkins and Wrightman[69] given at top of Fig. 16. The effect of pole tip fringing is practically to increase the pole face width W by an

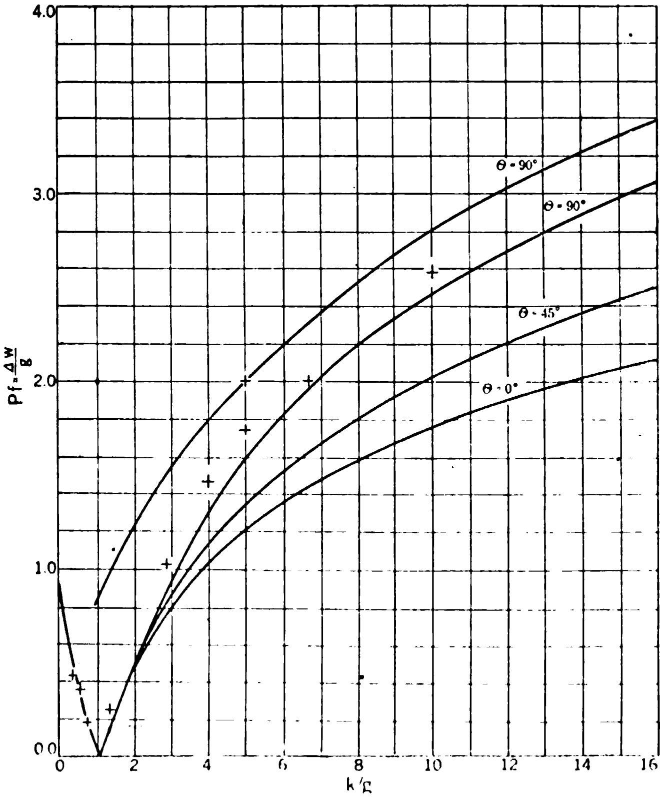

FIG. 16—PERMEANCE OF FRINGE FLUX FROM POLE-TIPS TO ARMATURE

amount ΔW in all, or one half that amount at each pole tip. This fringe is obtained from curves in Figs. 16 and 17 by multiplying the ordinates by the air-gap g. Analytically,

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[69] Inst. Elec. Eng. Jour., Vol. 29, pp. 436.

$$\Delta W = P_f g \tag{20}$$

The occasional negative value for the pole tip leakage in

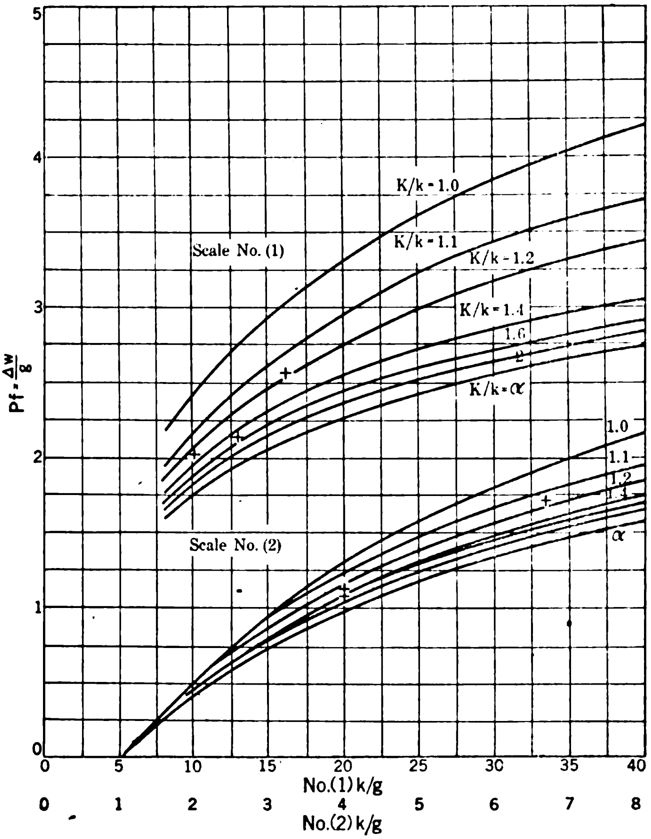

FIG. 17—FRINGE PERMEANCE FROM POLE-TIPS TO ARMATURE, $\theta = 0$

Fig. 18 really indicates that the pole tip fringing encroaches so far on the pole tip that the leakage flux is actually decreased thereby. Thus the error which is committed in Fig. 6 at the right, in assuming two different fluxes in the same place, is rendered plain. The amount to be added to the length of each pole to allow for this pole tip leakage is obtained by multiplying the ordinate of Fig. 18 by K, the distance between the pole cores nearest to the air-gap. Or, expressed analytically,

$$\Delta H = P_{lf} K \tag{21}$$

By referring to Fig. 5 it will be seen that some of the leakage flux passes directly from the pole-core to the pole yoke. This path is shorter than that assumed from the pole core to the neutral plane. As a consequence the permeance of the leakage flux is somewhat increased. Study of a field of flux somewhat similar by the method of complex quantities has indicated that this effect can be allowed for by adding to the length of the pole a fringe ΔH, which is approximately,

$$\Delta H = 0.3\, A^2/H \tag{22}$$

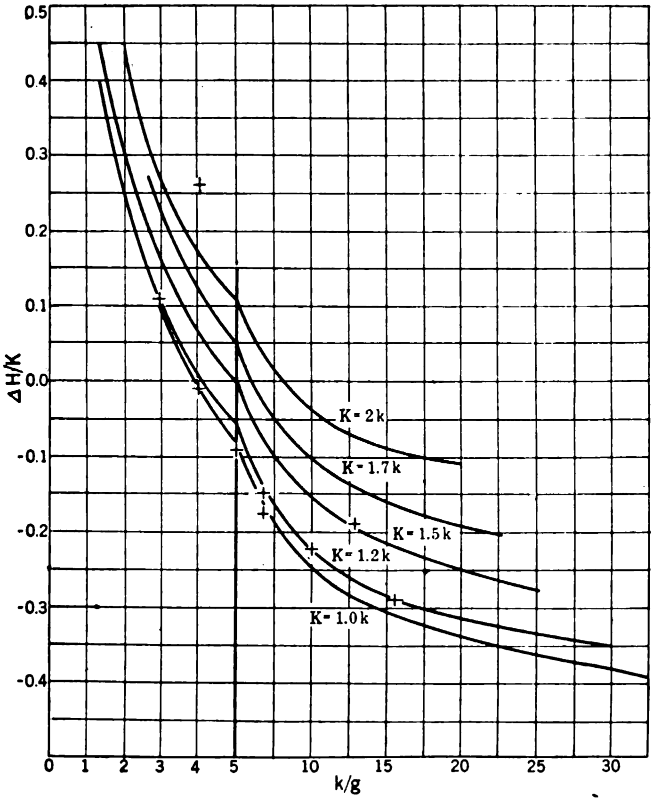

Fig. 18—Effect of Armature upon Pole Side Leakage Permeance

Here A is the half distance between the poles, and H is the length of the poles.

The distribution of leakage flux between circular poles of a multipolar machine is given in Fig. 19. The dotted lines give the best previous assumption, that of Dr. R. Pohl[70] which consists in imagining the lines of force to be involutes and straight lines. The cramped character of this assumption is readily seen. In Figs. 20 and 21 is shown the distribution between rectangular poles, and the dotted line approximation which is due to Prof. Forbes.[71] This assumption also cramps the field considerably.

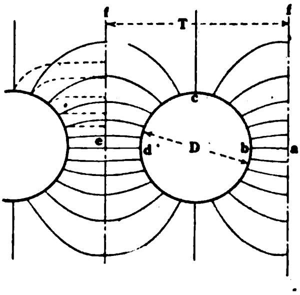

FIG. 19—LEAKAGE FLUX DISTRIBUTION BETWEEN ROUND POLES

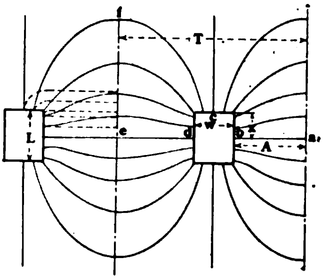

FIG. 20—LEAKAGE FLUX BETWEEN SMALL RECTANGULAR POLES

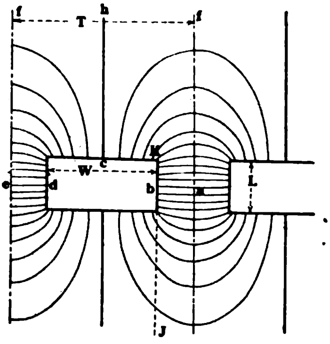

FIG. 21—LEAKAGE FLUX BETWEEN LARGE RECTANGULAR POLES

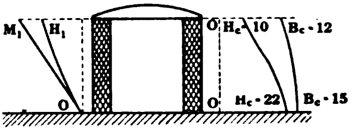

FIG. 22—EFFECT OF LEAKAGE UPON FLUX AND M. M. F. IN POLE-CORES

The effect of leakage upon pole saturation is shown graphically in Fig. 22. The free m.m.f. between the poles and the flux density in the interpolar regions, is shown at the left.

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[70] Jour. Inst. Elec. Eng., Jan. 1, 1914, Vol. 52, p. 120.

[71] Jour. Soc. Teleg. Eng. and Elec., Vol. 15, (1886), p. 551. See also Hawkins and Wallace, "The Dynamo", 3rd. Ed. p. 437.

Methods allowing for this effect are well known[72] and consist of counting only one-half of this leakage permeance as effective. The variation of the flux and ampere-turns in the pole core are shown at the right, both varying greatly. At present it is assumed that all the leakage enters at the pole tips; or, what is the same thing, the maximum value of ampere-turns in the pole-core is taken throughout its entire length. It would be better to assume the leakage flux to enter the core at some point nearer the pole-yoke, say one-half way up. The exact location could be determined by a graphical integration similar to that given by W. B. Hird[73] for the case of the reluctance of tapered and saturated armature teeth.

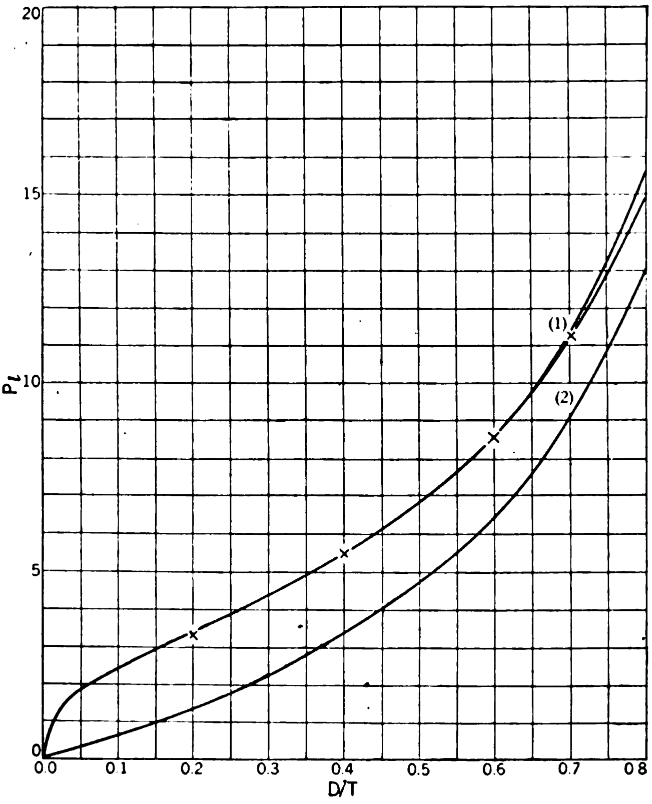

FIG. 23—LEAKAGE PERMEANCE FROM ROUND POLES TO NEUTRAL PLANE
1—Exact solution 2—Approximate solution

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[72] Hawkins and Wallace "The Dynamo", 3rd. Ed., p. 441. Pohl. Jour. Inst. Elec. Eng., *Loc. cit.*

[73] Jour. Inst. Elec. Eng. Vol. 29, p. 939.

The values of the leakage permeance from round poles to the neutral plane is plotted in Fig. 23 together with that calculated from Pohl's formula. The flux which leaves rectangular poles, as in Fig. 21, between the points *b c d* may be considered as divided into two parts. The first is that which would pass directly between the poles if the lines of force were straight; this is the pole face leakage. The remainder is fringe of the leakage flux, or what is called elsewhere the pole flank leakage. The formula for computing this leakage from the data is similar to equations (**15**), (**18**) and (**19**), and will not be given here. The result is plotted in Fig. 24, together with the customary ap-

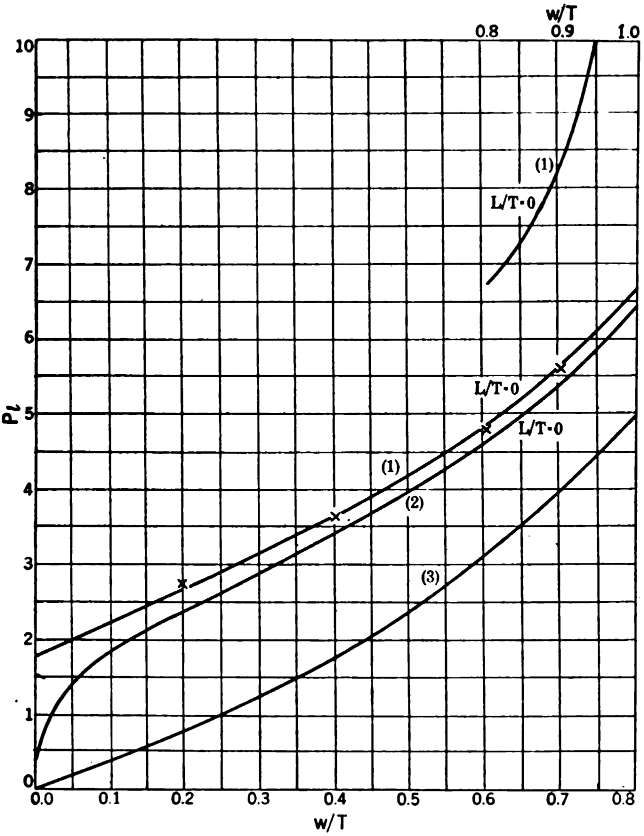

FIG. 24—LEAKAGE PERMEANCE FROM RECTANGULAR POLES TO NEUTRAL PLANE, IN EXCESS OF THAT BETWEEN THE POLES
(1) and (2) exact solutions—(3) approximate solution

proximate formula. In order to compute the leakage we multiply the ordinate taken from Fig. 24 by H the length of the poles increased ΔH for fringing at the roots, but not at the tip. It is to be noted that, except for very short machines axially, the upper of the two curves in Fig. 24 is the nearer the truth. In all cases the experimental data agreed closely with the upper curve.

The template used for determining the pole shoe flank permeance is shown in Fig. 25. This figure shows the method of trimming so as to get a number of different proportions with one sample. In Fig. 26 is shown the flux distribution; this corresponds to the right hand part of Fig. 5, the line d e being an assumed flux line. This figure was obtained graphically by the method of L. F. Richardson, given above. Lines 2, 4, and 6, and 9, 11, 13 etc. were drawn first. Then lines 1, 3, 5, 5, 8, 10, 12 etc. were drawn to test the accuracy of the preceding lines. For instance in the square 4, 6, s, u the line p r was compared with the line s t for equality. Considerable readjustment was necessary, and the reader will no doubt note improvements.

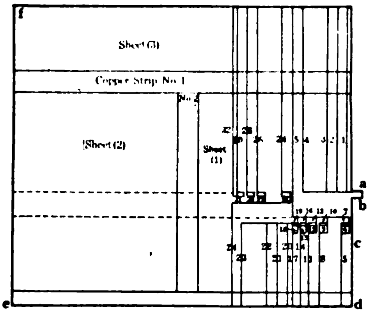

FIG. 25—METHODS OF MARKING AND CUTTING TEMPLATES OF SHEET METAL TO SIZE, SO AS TO ECONOMIZE MATERIAL

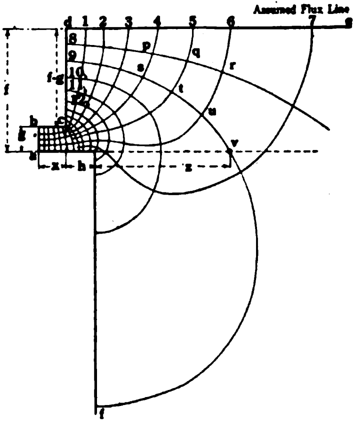

FIG. 26—DISTRIBUTION OF FLUX IN THE FRINGE FROM THE POLE-FLANKS TO THE ARMATURE—DETERMINED GRAPHICALLY

The flux leaving the pole in Fig. 26 between the points b c d may be divided in the usual way into air-gap flux, and the fringe flux. The formula for computing this from the data is similar to equations (**15**), (**18**) and (**19**). In this way the permeance in Figs. 27 and 28 were computed and plotted. It will be seen that this permeance depends on both the ratio of *f* to *g* and of *h* to *g*. This permeance, it is to be noted, is the combined pole shoe flank flux, both useful and leakage flux; and includes flux on both ends.

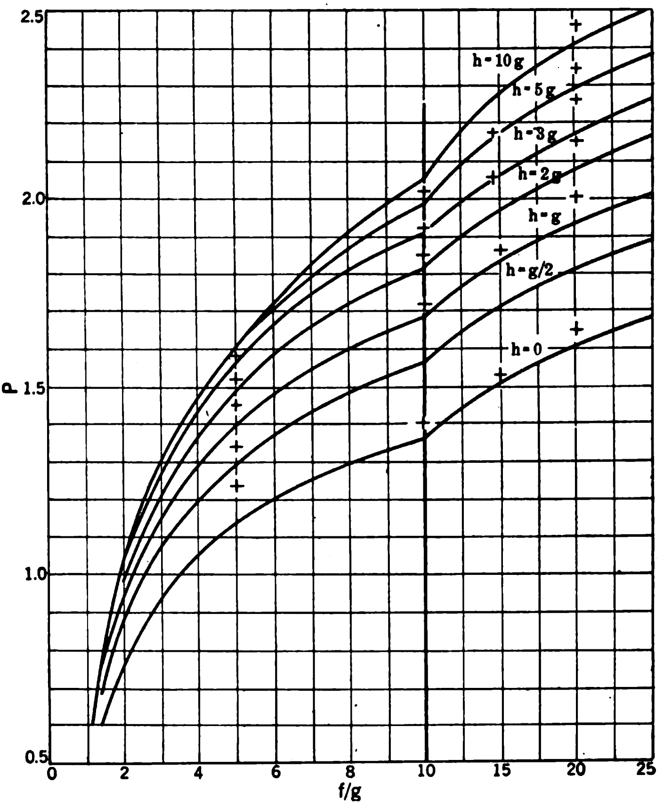

FIG. 27—PERMEANCE OF FRINGE FLUX FROM POLE-FLANKS TO ARMATURE SURFACE—FOR AN OVERHANGING ARMATURE. *i.e.* LONGER THAN POLES

It will be noted that the point *v* on line of flux No. 9 in Fig. 26, is also on the dotted line which is the projection of the armature coils. Thus the point *v* may be regarded as the trace of the armature coils. The flux between the line 9 *v f* and the armature links with the armature coils, and is useful. The flux between the line of 9 *v f* and the line *d e* is really leakage flux. Readings of the slide wire setting V_s were taken at various points shown on the dotted lines in Figs. 25 and 26, located at a distance z from the armature corner. The fraction of the total pole shoe flank flux that is useful was calculated by the formula,

$$\frac{P_u}{P} = \frac{(V_z - V_a)/K - (x/g)}{(V_e - V_a)/K - (x/g)} \tag{23}$$

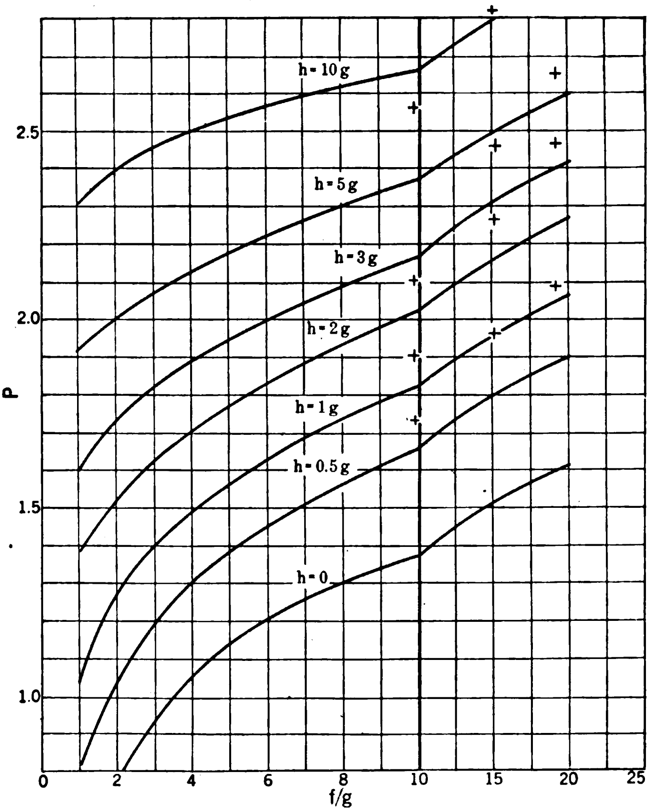

FIG. 28—PERMEANCE OF FRINGE FLUX FROM POLE FLANKS TO ARMATURE —FOR OVERHANGING FIELD POLES

This fraction was computed and plotted in Fig. 29. While this fraction theoretically should be a function of three variables, it was found it did not depend much upon the ratio of f to g. This rather fortunate coincidence permitted the results to be plotted in a single set of curves. Fig. 29 was not checked theoretically.

It is to be noted that the line *d e* is an *assumed* flux line. There is no natural boundary between the leakage lines and the fringe lines, and hence the point *d* has to be assumed in a somewhat arbitrary manner. Several rough trials have convinced the writer that the best location for the point *d* is at the junction of the pole shoe with the core, or at one quarter to one third of the width of the pole waist from the armature. Rough as this method is, it is hoped that it will be useful; a more accurate assumption is discussed in a later paragraph.

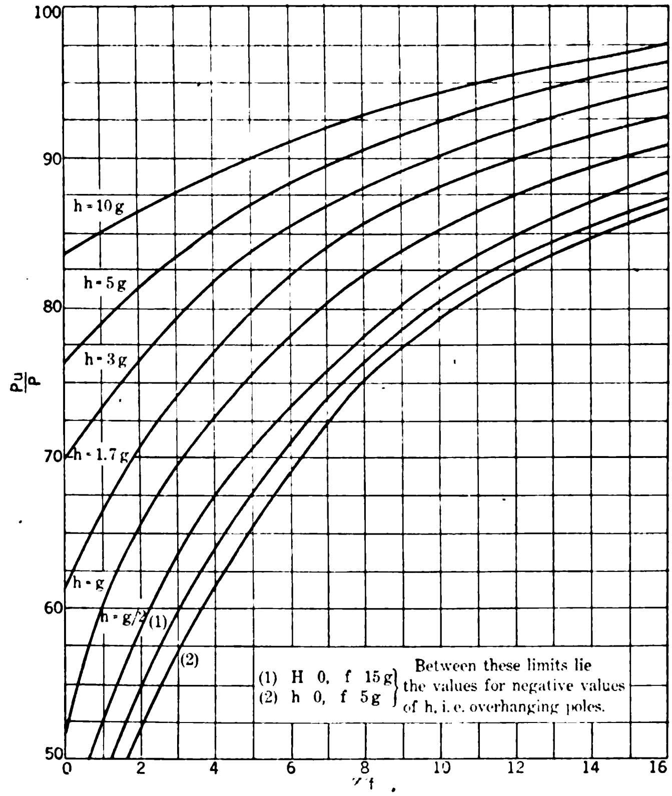

FIG. 29—CHART SHOWING THE PERCENTAGE OF THE POLE-FLANK FRINGE THAT IS USEFUL, FOR VARIOUS LOCATION OF THE ARMATURE COILS

In order to use Figs. 26, 27 and 28 we first estimate the width *f* of the pole shoe flux by the method of the preceding paragraph. From the working drawing of the machine we compute the ratios h/g and f/g, and from either Fig. 27 or Fig. 28 obtain the flank permeance. This we divide in two parts by means of Fig. 29, into the pole shoe flank fringe P_u and leakage, P_{lf}. The effect of the fringe is to add to the effective axial length of the air gap by an amount ΔL which is given by the equation,

$$\Delta L = P_u \, g \tag{24}$$

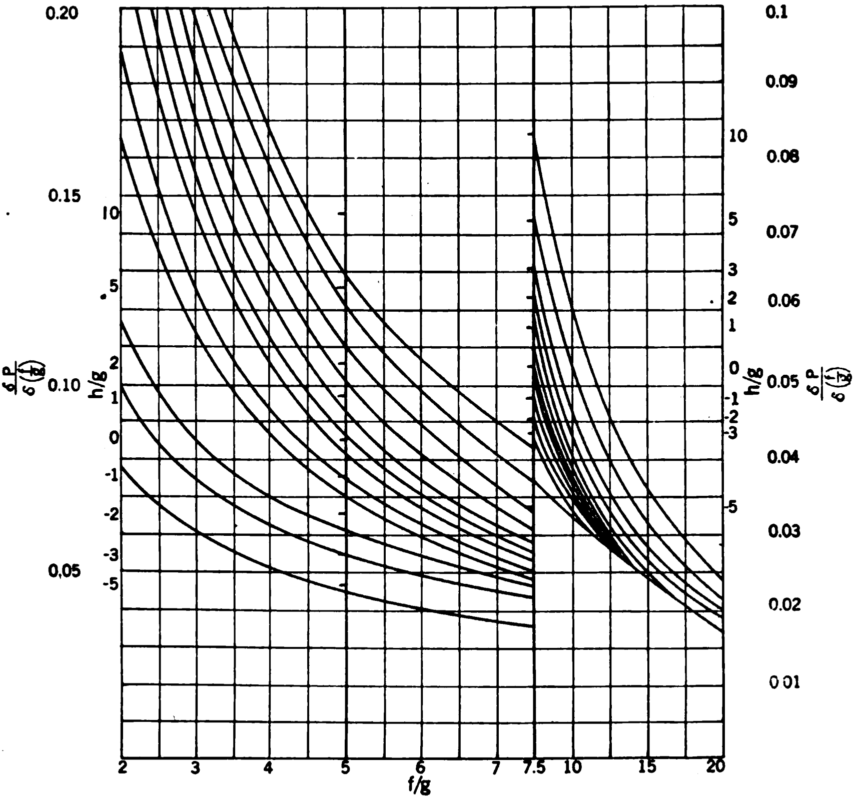

FIG. 30—CHART FOR DETERMINING WIDTH OF POLE FLANK FRINGE

The effect of the leakage fringe is to add to the leakage permeance by an amount,

$$P = P_{lf} \, (W + \Delta W), \tag{25}$$

where $W + \Delta W$ is the corrected width of the pole shoe next the armature.

The principle of "maximum effect" can be applied to the results given in Figs. 27 and 28, enabling one to pick out the most favorable value of the width of the pole shoe flank flux, f. This principle states that of two possible assumptions as to flux, that is nearer the truth which is the larger. Fig. 30 is the result of an attempt to apply this principle to the problem. For a maximum total permeance, the derivative of the pole shoe flank permeance with respect to f should be equal to that of the leakage permeance, taken with the minus sign. In symbols,

$$P_l = \frac{w}{g} \frac{d\,P}{d\,(f/g)} \quad . \qquad (26)$$

where P is given by Figs. 27 and 28, and P_l is the leakage fringe or pole flank leakage given by Fig. 24 for a definite pole waist width W. We may solve the above formula for the derivative, and by referring to Fig. 30 where this quantity is plotted, we can pick out the proper value of f/g at once.

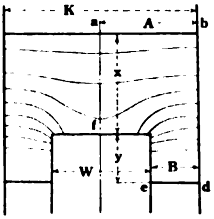

FIG. 31—FLUX DISTRIBUTION BETWEEN MAIN AND INTER-POLES

The results given in Figs. 27–30 are somewhat complicated, and good service could be done by inventing an empirical formula which would fit the results fairly closely. The only previous attempt to deal with the matter adequately is an article by M. Legros[74] whose formulas are too complicated to give here.

The flux distribution between the poles of an interpolar machine (as produced by the m.m.f. upon the main poles) is shown in Fig. 31. There is a fringe of permeance over that computed on the assumption of straight lines of force between the poles. This permeance is computed from the data in the usual manner and plotted in Fig. 32. The permeance is that in excess of computed permeance, up to the neutral plane only, for both ends of the interpoles and for two interpoles.

The leakage flux distribution inside a slot is shown in Figs. 33 and 34. The template cut in this case is similar to that cut for the preceding case. Both cases are similar to an electrical problem solved by C. H. Lees.[75] The fringe permeance is defined in the usual way as the excess of the total permeance over that computed between the parallel parts of the slot. The formula for computing the fringe of permeance is from the experimental data in similar to those previously mentioned. The permeance as plotted in Fig. 35 is that for the whole slot, per centimeter of axial length. Various approximate formulae have been proposed[76] most of which are based upon assuming the lines across the slot to be straight. These formulas are compared with the correct formula in Fig. 36 for the tooth tip angle of 45 deg.

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[74] Eclairage Electrique, Vol. 30, p. 437; Vol. 51, p. 12.

[75] *Phil. Mag. Loc. cit.*

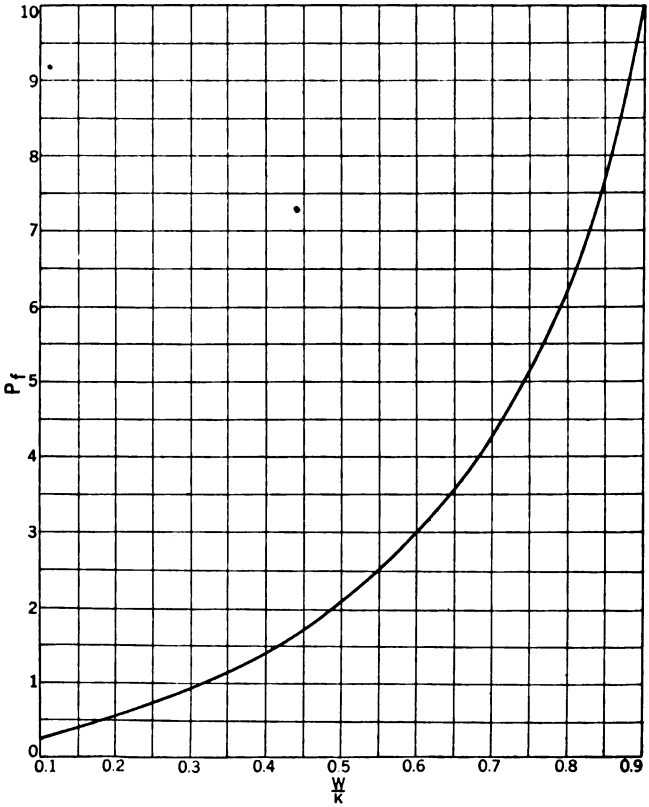

FIG. 32—FRINGE OF LEAKAGE PERMEANCE FROM MAIN TO INTERPOLES

All of these formulas give null result when the pole tip angle is zero, and hence are in considerable error.

In Fig. 37 we have the field of flux produced by one armature coil embedded in nearly closed slots. At a distance $x = n \lambda$ from the first coil there is a second coil with a line of flux entering

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[76] E. Arnold, Wechselstromtechnik, Vol. 4, 1st Ed., p. 44. C. A. Adams, A. I. E. E. TRANS., Vol. 24, (1905), p. 335. J. Rezelman, Lumiere Electrique, Vol. 10, (1910), p. 293.

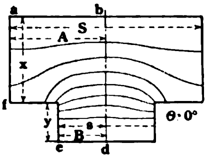

FIG. 33—DISTRIBUTION OF LEAKAGE FLUX IN SEMI-CLOSED SLOTS

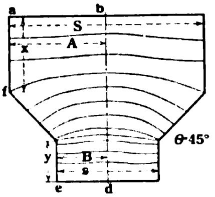

FIG. 34—DISTRIBUTION OF LEAKAGE FLUX IN SEMI-CLOSED SLOTS

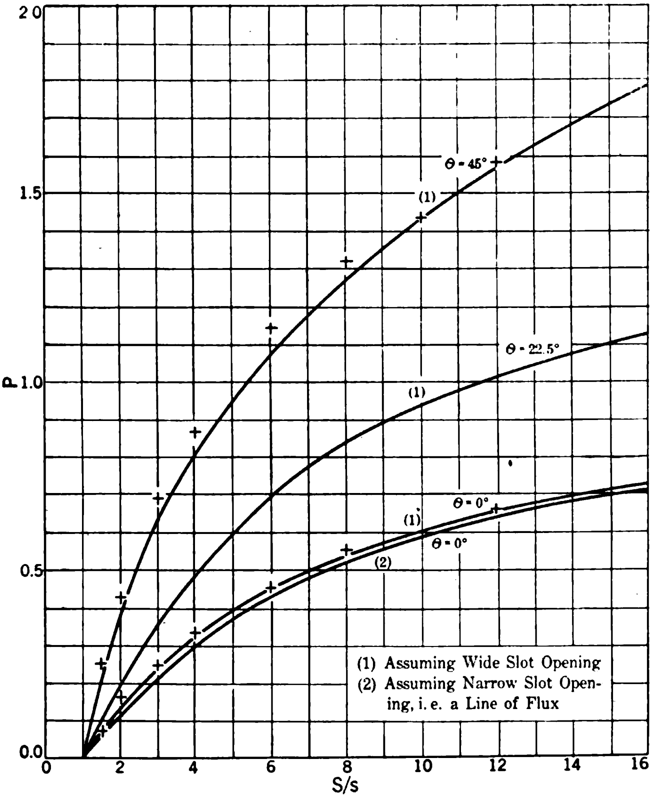

FIG. 35—PERMEANCE OF INTERNAL FRINGE OF SLOT LEAKAGE FLUX

the center of its slot. The flux inside this line links with only one coil but that between this line and the center of the pole is flux of mutual induction. The permeance of this flux of mutual induction was evaluated theoretically by applying the method outlined in the historical section and is plotted in Fig. 39.

The flux of self-induction is the whole flux up to the mouth of the slot. In Fig. 38 is shown a detail of the armature leakage flux near the slot opening. It will be observed that close to the slot the lines of flux change gradually from a semi-circular form to straight lines. The fringe of the flux of self-induction outside of the slot is defined in the usual way as the excess over what would pass inside the slot opening, were the lines of force straight. The permeance of the flux was calculated and plotted in Fig. 39 against x which is half of the slot opening, namely

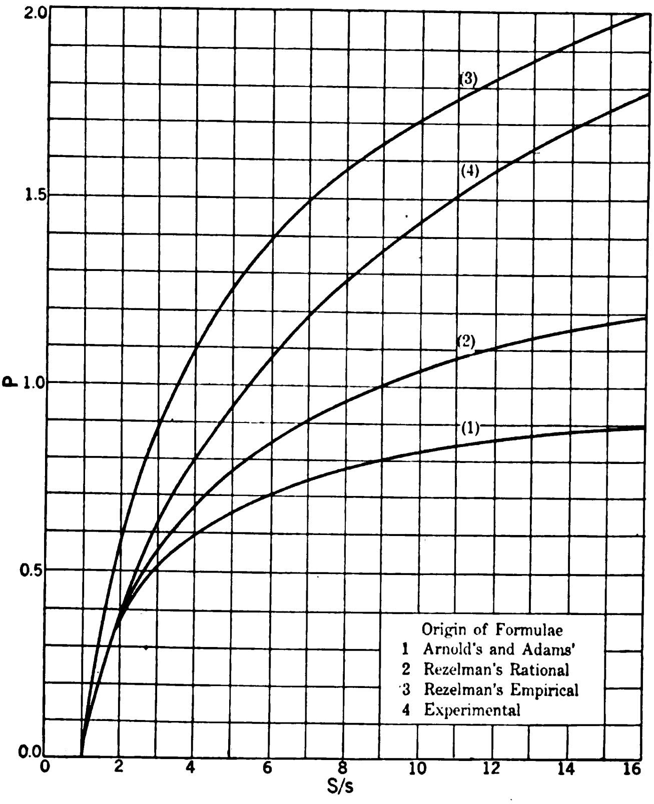

FIG. 36—COMPARISON OF VARIOUS FORMULAE FOR SLOT LEAKAGE

($s/2$). The result is correct only provided the slot width is small as compared to the pole pitch.

In Fig. 39 is also plotted Arnold's[77] formula for self and mutual induction. This formula is based upon the assumption

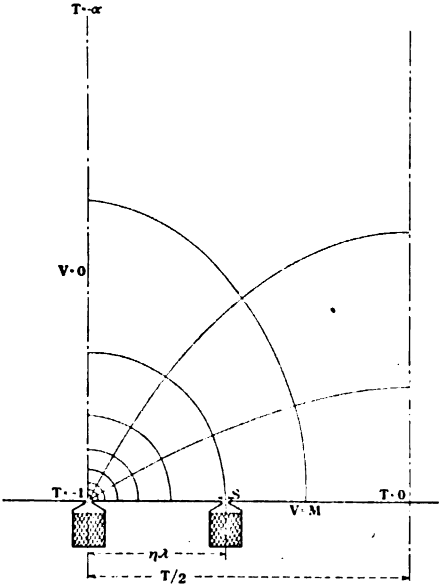

Fig. 37—Leakage Flux Distribution due to a Concentrated Aramature Winding

that the leakage lines are arcs of circles and straight lines. His results are in error theoretically, in that he integrates over the whole pole pitch. This error is corrected in the second edition.

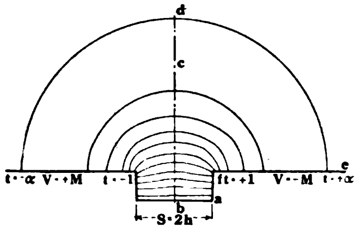

Fig. 38—Leakage Flux Distribution near the Mouth of a Slot

Fig. 39 can be used to determine self and mutual induction for the flux outside the slots, provided the field poles are removed from the armature. This is the case when the reactance of an alternator is determined from experiment. However, it is another question whether the reactance so determined has much relation to that of the machine completely assembled. No correction should be made for the curvature of the armature surface, since a short theoretical investigation proved that it is not necessary. This is in contradiction to Arnold's and Rezelman's recommendation. When there are a number of slots per phase and per pole, the application of Fig. 39 becomes difficult, and further simplification becomes desirable.

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[77] Wechselstromtechnik, 1st Ed. Vol. 4, (1904), p. 44. See also Rezelman, Lumiere Electrique, Vol. 10, p. 259.

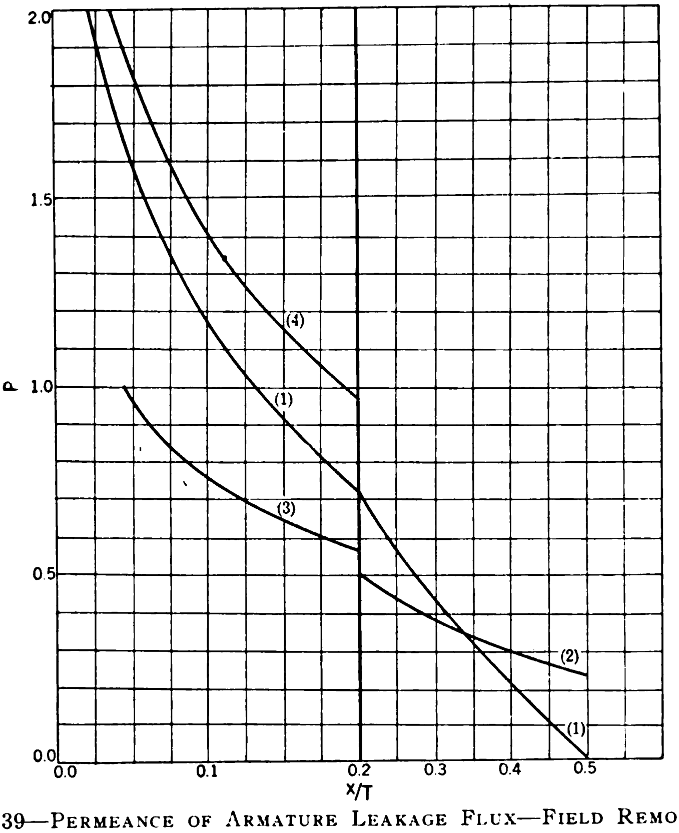

FIG. 39—PERMEANCE OF ARMATURE LEAKAGE FLUX—FIELD REMOVED

(1) and (2)—Mutual induction (3) and (4)—Self induction

(1) and (4)—Exact Formulas (2) and (3)—Arnold's formulas

The leakage flux set up by an armature winding in the region outside the slots, links in part with each slot individually, and in part with more than one slot. It is convenient therefore, to calculate the inductance due to the leakage flux as if it linked with the whole of the group of conductors belonging to one phase under one pole. This inductance should include the effect of mutual induction between the phases. On the other hand, the leakage flux set up inside the slots is most conveniently calculated separately.

Using Fig. 39, and taking into account the factors mentioned, the writer worked out the equivalent leakage permeance of the flux set up in the region outside the slots. It was found that, between the limits of one to twelve slots per phase per pole, the equivalent leakage permeance was practically a constant; providing that a certain amount be added to the leakage permeance of the slots, for the flux just outside the slot opening. The equivalent leakage (geometric) permeance was found to be

$$P_{eq} = 0.725 \text{ and } 1.19 \qquad \textbf{(27)}$$

for two and three phase machines respectively. The fringe of permeance to be added to that inside the slots was found and is recorded in table 2. The best previous method for computing the equivalent leakage permeance was that proposed by Schenkel[78] Applying this method the writer obtained the values 0.51 and 0.86 for two-phase and three-phase machines respectively.

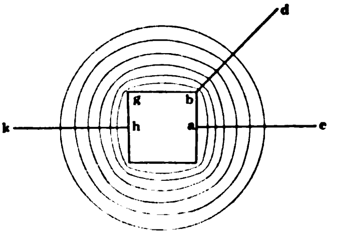

FIG. 40—EQUIPOTENTIAL SURFACES AROUND A SQUARE WIRE

TABLE 2—VALUES OF EXTERNAL FRINGE OF SLOT LEAKAGE PERMEANCE.

(s/λ) =	0.60	0.50	0.40	0.30	0.20	0.15	0.10	0.05	0.025
$\triangle P_s$ =	- 0.20	—0.10	—0.03	+0.10	+0.30	+0.40	+0.55	+0.85	+1.200

In order to use the above results to obtain the inductance per phase of a machine, we first add to the fringe of permeance belonging to the slot and obtain the total slot permeance P_s. Then, if C_s is the number of conductors per slot and C_{pp} are the number of conductors per pole, and per phase, P the number of poles, and S the number of slots per phase, and L the effective length of the machine; the inductance of the machine, exclusive of that of the end connections, is

$$L = (4\,\pi/10)\,(S\,C^2_s\,P_s\,L + P\,C_{pp}^2\,P_{eq}\,L)\,10^{-8} \qquad \textbf{(28)}$$

The electrostatic equipotential surfaces around a square conductor, are shown in Fig. 40. The capacity of a rectangular wire of dimensions a and b was investigated mathematically and found to be given by the following equation.

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[78] Electrotechnik und Maschinenbau, Vol. 6, (Feb. 1901), p. 54.

$$C = \frac{\pi K_a L}{L_n\ (KD/\text{perimeter})} \tag{29}$$

where C is the capacity between two wires D cm apart. K_a is the dielectric constant for air, L is the length of the wire in cm. and K is a factor plotted in Fig. 41, the perimeter of the wire being $2\ (a + b)$.

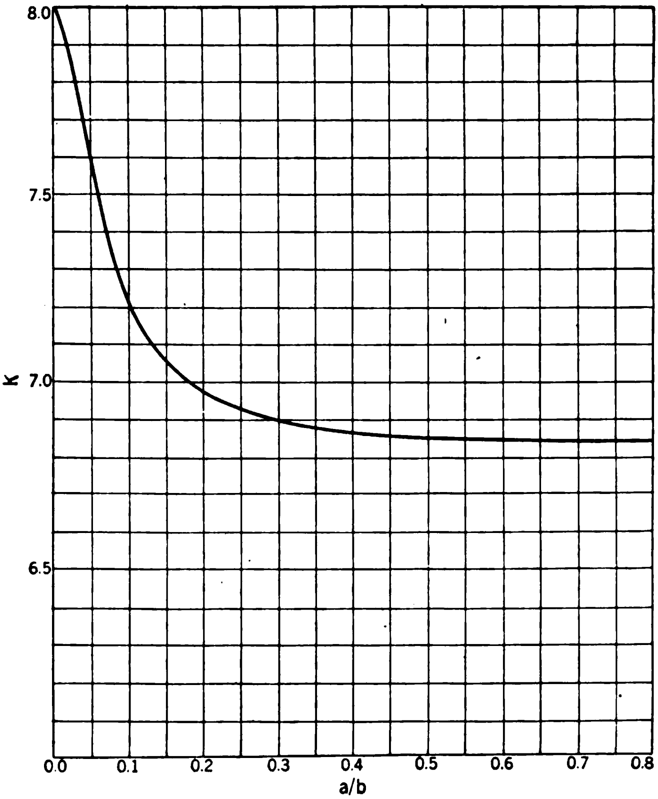

FIG. 41—FACTOR FOR DETERMINING CAPACITY OF RECTANGULAR WIRE

The above cases comprise all those of which the writer is prepared to report the permeance. However, the flux distribution in the cores of various machines was studied, also that in the air-gap of alternators. Owing to saturation, the reluctance as measured by experiment in these cases would not be of great value; and for this reason it was not calculated. The reluctance of the air gap of alternators was omitted because the assumed shape of the pole is not used.

The flux distribution in the core of a transformer is shown in Figs. 42 and 43. While the flux lines could have been obtained by soldering electrodes to the broken lines ***e f m n*** and ***g h k l*** this would have been awkward. By soldering electrodes to the edges ***e g*** and ***l n*** and passing current through the strip, the equipotential lines ***f h*** and ***m k*** were traced out. The L-shaped strip was then cut into three lengths ***e f g h***, ***f h k m***, and ***k l m n***. The flux lines were then very easily obtained by soldering electrodes to the lines ***g h***, ***h k***, ***k l***, ***e f***, ***f m***, and ***m n***, and passing current through the three strips in the usual way. The writer is indebted to Mr. E. M. Shepard, Cornell' 13, for the experimental work involved in this problem.

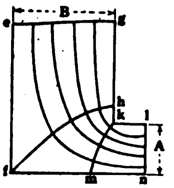

FIG. 42—FLUX DISTRIBUTION IN CORNER OF A TRANSFORMER

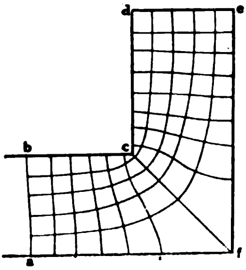

FIG. 43—FLUX DISTRIBUTION IN THE CORNER OF A TRANSFORMER

The flux within the core of an armature is shown in Fig. 44; this was suggested by test results published by Dr. Thornton.[79] The template has to be laid out with a calculated curve, the equation of which is obtained by the theory outlined earlier in the paper. This equation is,

$$(x/R)\,[\,(x/R)^2 - 3(y/R)^2\,] = 1 \qquad \textbf{(30)}$$

This figure was determined from experiments and compared with the curves published by Dr. Thornton and found to agree completely. This work was also performed by Mr. E. M. Shepard.

The flux distributions shown in Figs. 45, 46 and 47 was determined by calculation only, but the excellent agreement between experiment and theory in all other cases indicates that they should be reliable.

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[79] *I. E. E. Jour. Loc. cit.*

The theoretical shape of pole shoe required to give an absolutely sine wave of voltage in an alternator was calculated by the mathematical theory outlined in the Historical Section, for a two-pole alternator. The equation of this pole shoe was,

$$(y/R) - [yR/(x^2 + y^2)] = 0.19 \qquad \mathbf{(31)}$$

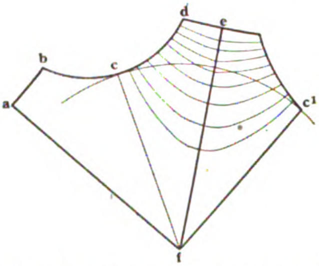

Fig. 44—Flux Distribution in the Armature Core of a Six-Pole Machine

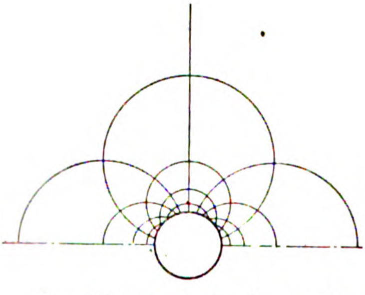

Fig. 46—Leakage Flux Distribution Due to a Two-Pole Alternator Armature Removed from Its Field

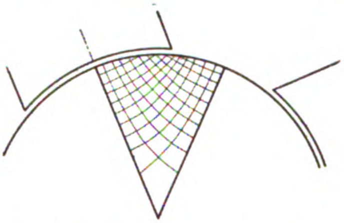

Fig. 45—Flux Distribution in a Four-Pole Armature with Uniform Flux Density in the Air-Gap

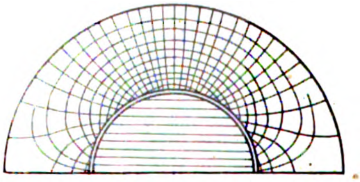

Fig. 47—Flux Distribution in a Two-Pole Induction Motor

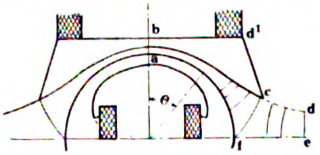

Fig. 48—Pole-Shoes Shaped to Give Sine-Wave E.M.F.

A template was cut to this form and the field distribution shown in Fig. 48 measured. The flux density distribution on the armature corresponding electrically to the volts drop per cm. of circumference of the circle, *c f*, was measured experimentally. This drop is plotted in Fig. 49. The experiment was repeated with a template shaped like *a b c d' e f* in Fig. 48 with the pole piece cut away in a convenient manner. This result also is plotted in Fig. 49. The first curve is an exact sine wave. The shape of the pole in a four-pole machine is similar to that in Fig. 48.

The mathematical theory is readily adapted to finding the correct pole shape for any shaped wave of flux desired. The application is not difficult as the writer solved a particular case of this sort in a short time.

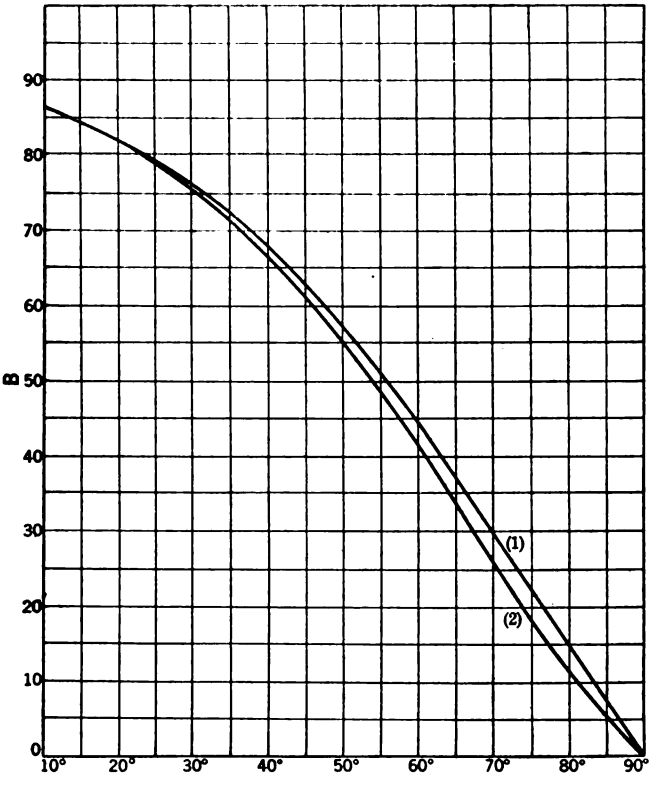

FIG. 49—FLUX DENSITY DISTRIBUTION UNDER POLES OF ALTERNATOR
(1) Poles shaped for sine wave (2) Same pole tips cut away at convenient angle

It is believed that the most convenient way to use the results of this paper is by means of the curves shown. One no longer uses Frohlich's equation for saturation of iron, but the magnetization curve itself. It is more convenient to use curves of core loss than to calculate it from its co-efficients. Likewise a set of curves like those in this paper for magnetic circuits of various forms, would facilitate magnetic calculations. (Those who prefer a formula, however, can use the equations for the curves which will be found in an appendix for reference.)

IV. ACCURACY OF RESULTS

The accuracy of the assumptions made in the preceding two-dimensional magnetic fields, when used to compute the total reluctance of a dynamo is the next topic to discuss. This we may do by using a theorem due to Lord Rayleigh.[80] If in a conducting medium we insert thin laminae of perfectly insulating material, the total resistance of the field will be increased. The only exception to this rule is when we place these insulating surfaces so as to co-incide with the natural lines of flow, when the total resistance is unchanged. When we assume arbitrary flux lines, as we do for simplicity when computing the permeance, we are in effect imagining the course of the lines of force restrained by guiding insulating surfaces. Thus any formula which is derived upon this basis gives too small a permeance.

Of two different assumptions as to the course of the lines of force, the one yielding the larger total permeance, is the most nearly correct. The closer the assumed lines of force agree with the actual lines of force, the less the error which is made. Of two possible constrained distributions, the one subject to the most restraint is the most in error.

The results shown in this paper are of necessity too small, by the extent that the assumptions made in Fig. 6 do violence to the natural course of the lines of force. Where the guiding surfaces merely separate one field from another, as the pole flank leakage from the pole shoe flank fringe and the pole shoe leakage, the error should be very small. The only place where the error could be considerable, would be where the surfaces assumed prevented the flux from reaching the other side. Thus in Fig. 6 the leakage flux is prevented from expanding beyond the pole yoke. Lord Rayleigh also gave a method for obtaining a superior limit to the permeance, but this was not applied by the writer.

It will be found, with three apparent exceptions that the results shown in this paper are larger than those obtained by any of the approximations used hitherto. It may be concluded, therefore, that the results here given are closer to the truth. The three exceptions are Figs. 16, 36, and 39. In Fig. 16 the approximate curve given by Hawkins and Wrightman is based upon an assumption of the lines of force which encroaches upon the leakage field. Thus, although the permeance of the flux from the pole tip to the armature seems larger than it really is, the total permeance will be found to be less. In Fig. 36, curve No. 3, for a tooth tip angle of $\theta = 45$ deg., the approximation is larger than the curve here given. It is to be noted, however, that this is a purely empirical curve and does not correspond to any possible assumption of the lines of force. In Fig. 39 the formula as given by Arnold has an error in the integration. When this integration is performed correctly this apparent discrepancy with the principle disappears.

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[80] Theory of Sound, Vol. 2, Sect. 305, p. 175. See also V. Karpen, Comptes Rendus, Vol. 134, pp. 88-90.

V. CONCLUSIONS

Most of the results in this paper are apparent, but they may be briefly summarized.

(1) In magnetic circuit calculations a considerable portion of the magnetic field is irregular.

(2) Many of the methods in vogue for computing the reluctance of irregular magnetic fields are very inaccurate.

(3) Accuracy of an equal order of magnitude is desirable in all parts of a given problem. In particular it is believed that greater accuracy in leakage flux calculations would be desirable.

(4) The reluctance of irregular magnetic fields occurring in electrical machinery, can be estimated fairly well by studying various two-dimensional flux distributions.

(5) A knowledge of the properties of the functions of complex numbers, enables one to compute the reluctance of many two-dimensional magnetic fields.

(6) Particular cases on the reluctance of irregular magnetic fields, are easily studied experimentally by the use of templates of the proper shape cut from sheets of high resistance metal.

(7) The entire field around a dynamo electric machine has been divided into sections, and the reluctance of each section determined to a greater degree of approximation than before. Many factors have been shown to have negligible effect, and in many cases present methods have been shown to be greatly in error.

(8) A number of other magnetic fields have been studied; in particular, the field around a square wire, the flux distribution in transformer cores, dynamo cores, and the air gap of alternators.

(9) It is of advantage to use graphical charts of permeance rather than empirical formulae.

(10) There are other cases of interest and value in the reluctance of irregular magnetic fields yet to be solved.

The writer wishes to acknowledge obligation to Cornell University in furnishing facilities for the experimental work, To Professors J. Macmahon, V. Karapetoff, and F. Bedell, and to Mr. F. W. Carter for suggestions, and to Mr. E. M. Shepard for valuable assistance with the experiments.

APPENDIX I.

MATHEMATICAL RESULTS

The fringe of tooth permeance for wide teeth and deep slots as shown in Fig. 9 is

$$P_f = \frac{2\pi}{\pi g} \cot^{-1} (S/2g) + \frac{2}{\pi} Ln \left[1 + (S/2g)^2\right] \qquad (32)$$

when the pole tip angle θ is 90 deg. The symbol *Ln* indicates the natural logarithm. When the pole tip angle is 0 deg.,

$$P_f = \frac{1}{\pi} Ln \frac{\sqrt{a} + 1}{\sqrt{a} - 1} + \frac{4}{\pi (\sqrt{a} + 1)} \qquad (33)$$

where the parameter a is determined from the equation,

$$\frac{S}{2g} = \frac{1}{\pi} Ln \frac{\sqrt{a} + 1}{\sqrt{a} - 1} + \frac{2\sqrt{a}}{\pi (a - 1)} \qquad (34)$$

When the pole tip angle θ is 45 deg.,

$$P_f = \frac{2}{\pi} Ln (4/a) + \frac{1}{\pi} \int_0^a \frac{\sqrt{1 + t} - \left(1 - \frac{t}{a}\right)^{0.75}}{t \sqrt{t + 1}} dt \qquad (35)$$

where the integration is performed graphically and a determined from the following equation.

$$\frac{\pi S}{2g} = \int_a^{+1} \frac{\left(1 + \frac{t}{a}\right)^{0.75}}{t \sqrt{1 - t}} dt$$

$$+ \int_0^a \frac{\left(1 + \frac{t}{a}\right)^{\frac{3}{4}} \sqrt{1 + t} - \left(1 - \frac{t}{a}\right)^{\frac{3}{4}} \sqrt{1 - t}}{t \sqrt{1 - t^2}} dt \qquad (36)$$

For infinitely narrow teeth, we have with a pole tip angle of 90 deg.,

$$P_f = 2\,\frac{K\left(\operatorname{sech}\frac{\pi g}{s}\right)}{K\left(\tanh\frac{\pi g}{s}\right)} \tag{37}$$

where K is the complete elliptic integral of the first kind tabulated in Pierces' Tables of Integrals page 117. For large values of the air gap, and finite width of the teeth, the excess reluctance of the air gap; plotted in Fig. 11 is

$$R_e = \frac{1}{\pi}\left(1 + \frac{S}{\lambda}\right) Ln\left(1 + \frac{S}{\lambda}\right) + \frac{1}{\pi}\left(1 - \frac{S}{\lambda}\right) Ln\left(1 - \frac{S}{\lambda}\right) \tag{38}$$

When the slots are shallow, and the teeth are infinitely narrow, the fringe permeance plotted in Fig. 10 is given by the equation

$$P_f = 2\,\frac{K\,(a)}{K\,(\sqrt{1-a^2})} \tag{39}$$

where a is a parameter which has to be determined, together with another parameter b from the following equations.

$$\frac{s}{d+g} = \frac{K\,(b)}{K\,(\sqrt{1-b^2})} \tag{40}$$

$$\frac{d}{d+g} = \frac{F\left(\sqrt{1-b^2},\sqrt{\frac{a^2-b^2}{a^2\,(1-b^2)}}\right)}{K\,(\sqrt{1-b^2})} \tag{41}$$

The permeance from the two pole tips of a machine to the armature, is less than that from tooth tips of the same shape by an amount

$$P_f = 2\,\frac{Ln\,(4)}{\pi} \tag{42}$$

Thus the permeance curves in Fig. 16 are similar in shape to those in Fig. 9, and can be plotted by applying the above correction P_f to equations (**32**), (**33**), and (**35**).

The permeance from the pole tips of a machine with projecting pole tips, as shown in Fig. 15 and plotted in Fig. 17 is given by the equation

$$P_f = \frac{1}{\pi} Ln \left(\frac{1 + b^2}{4\, b^2} \right) + \frac{K}{2 \pi g} \cos^{-1} \left(\frac{1 - b^2}{1 + b^2} \right) - \frac{L\, K}{K\, g} \quad \textbf{(43)}$$

where b is a root of the following equation.

$$\frac{L}{K} = \frac{1}{2 \pi} \cos^{-1} \left(\frac{1 - b^2 + 2b \frac{2g}{K}}{1 + b^2} \right)$$

$$- \frac{2g}{\pi K} Ln \left\{ \frac{2 \sqrt{b \left(b - \frac{2g}{K} \right) \left(1 + \frac{2\,bg}{K} \right)} + 2b + (b^2 - 1) \frac{2g}{K}}{(1 + b^2)\,(2g/K)} \right\}$$

(44)

The permeance of the pole tip leakage fringe shown in Fig. 18 is given by,

$$P_{lf} = \frac{2g}{\pi K} \cos^{-1} \left(\frac{b^2 - 1}{b^2 + 1} \right) - \frac{1}{\pi} Ln \frac{4}{1 + b^2} \quad \textbf{(45)}$$

the parameter b being the same as in the previous equation.

The leakage permeance from round poles to the neutral plane as plotted in Fig. 23, is given by the following equation:

$$P_l = \frac{\pi}{2} \left\{ \frac{\cot^2 \frac{\pi r}{2T} + \coth^2 \frac{\pi r}{2T}}{\coth^2 \frac{\pi r}{2T}\, Ln \cot \frac{\pi r}{2T} - \cot^2 \frac{\pi r}{2T}\, Ln \coth \frac{\pi r}{2T}} \right\}$$

(46)

The fringe of leakage permeance from both ends of long rectangular poles to the neutral plane between the poles of a multipolar machine as plotted in Fig. 24, is

$$P_f = \frac{4}{\pi} \left(\frac{T}{K} + 1 \right) Ln \left(\frac{T}{K} + 1 \right) + \frac{4}{\pi} \left(\frac{T}{K} - 1 \right) Ln \left(\frac{T}{K} - 1 \right)$$

(47)

In machines of very short axial length, the same permeance, as plotted in Fig. 24, is,

$$P_1 = 4\,\frac{K\left(\cos\dfrac{\pi K}{2T}\right)}{K\left(\sin\dfrac{\pi K}{2T}\right)}. \tag{48}$$

The total pole shoe flank permeance, to the armature end, which is plotted in Figs. 27 and 28 is

$$P = \frac{K\,(b)}{K\sqrt{1-b^2}} \tag{49}$$

where the two parameters "*b*" and "*c*" are determined from the equations following, when the armature projects beyond the field pole. Note that E is the elliptic integral of the second kind, found in Pierces' tables pp. 117 and 119.

$$\frac{g}{f} = 1 - \frac{E\,(c,\,b)}{E\,(c,\,90^\circ)} \tag{50}$$

$$\frac{h}{f} = \frac{E\,(\sqrt{1-c^2}) - c^2 K\,(\sqrt{1-c^2})}{E\,(c)} \tag{51}$$

When the field, however, projects beyond the armature, the parameters "*b*" and "*c*" are given by the following equations,

$$\frac{g}{h} = \frac{\displaystyle\int_0^{\cos^{-1}b} \sqrt{\sec^2\theta - c^2}\,\sec\theta\,d\theta}{\sqrt{c}\,\sqrt{1-c^2}\,E\,(\sqrt{1-c^2}) - \sqrt{c^5}\,\sqrt{1-c^2}\,K\,(\sqrt{1-c^2})} \tag{52}$$

$$\frac{f-g}{h} = \frac{(1/c)\;E\,(c) - (1-c^2)\;K\,(c)}{\sqrt{1-c^2}\;E\,(\sqrt{1-c^2}) - c^2\sqrt{1-c^2}\;K\,(\sqrt{1-c^2})}. \tag{53}$$

The fringe of permeance from the main poles to the interpoles of a dynamo, which is plotted in Fig. 32, is

$$P_f = \frac{2}{\pi} Ln\left(\frac{1}{4}\right)\left(\frac{K}{K-W} - \frac{K-W}{K}\right) + \frac{2}{\pi}\left(\frac{K}{K-W} + \frac{K-W}{K}\right) Ln\left(\frac{2K}{W} - 1\right) \tag{54}$$

The permeance of the fringe of flux on the inside of an armature slot shown in Figs. 33, 34 and 35 is,

$$P = \frac{1}{2\pi} Ln \frac{1}{4} \left(\frac{S}{s} - \frac{s}{S}\right) + \frac{1}{2\pi} \left(\frac{S}{s} + \frac{s}{S}\right) Ln \left(\frac{S+s}{S-s}\right) \quad (55)$$

when the angle of the tooth tip is 0°: when the angle is θ, where θ is (π/n), we have the equation,

$$P = \frac{1}{2\theta} Ln\,(S/s) + \frac{1}{\pi} \int_0^\infty \left\{ \sqrt[2n]{\frac{e^x - (S/s)^n}{e^x - 1}} - \sqrt[2n]{\frac{e^x - 1}{e^x - (S/s)^n}} \right\}^2 dx \quad (56)$$

The permeance of the armature leakage flux of mutual induction, outside the slot is plotted in Fig. 39 and is given by the equation,

$$P = \frac{2}{\pi} Ln \cot \frac{\pi x}{2T} \quad (57)$$

where the distance $x = n\lambda$. The same formula will give the self-induction provided we take $x = (S/2)$, and add to the permeance a constant C. The constant C has a value 0.241 as given by

$$C = \frac{1}{\pi} + \frac{Ln\ (\pi/4)}{\pi} \quad (58)$$

The capacity between wire of rectangular cross section is given by equation (**20**) where the constant K is given by,

$$(K/8) = c\ \sqrt{1-c^2}\ E\ (\sqrt{1-c^2}) + E(c) - c^3\ \sqrt{1-c^2}\ K\ \sqrt{1-c^2} - (1-c^2)\ K(c) \quad (59)$$

The constant K and the elliptic function K are not to be confused.

The parameter c may be determined from equation (**53**) providing that we read (b/a) in place of $(f-g)/h$.

APPENDIX II

METHODS OF COMPUTING RELUCTANCE THEORETICALLY

The method of determining the reluctance of irregular magnetic fields mathematically is best understood by working out two typical cases. The two most representative cases are; the fringe permeance from the sides of infinitely narrow teeth, as plotted in Fig. 9, and the fringe of leakage permeance from rectangular poles, as plotted in Fig. 24.

If, in Fig. 7, we continue the sides of the teeth across the air gap, as is shown by the lines $n\ m$ and $o\ p$, these lines will be flux lines. We will convert this conductor by Schwartz' theorem into a half plane with straight line boundary, and then into a rectangle. The point n corresponds in the t plane to the point $t = -a$, m to the point $t = -1$, o to the point $t = +1$, and p to the point $t = +a$. If the slots are of infinite depth the point $t = \infty$ corresponds to the deepest part of the slot. In the W plane, the line $n\ m$ corresponds to the line $\phi = 0$, $m\ o$ to the line $V = 0$, $o\ p$ to the line $\phi = \phi_m$, and both nQ and Rp in part to the equipotential line $V = M$. By Schwartz's theorem we have,

$$Z = \int C \frac{dt}{\sqrt{t^2-1}} \qquad (60)$$

$$W = \int K \frac{dt}{\sqrt{(t^2-1)\ (t^2-a^2)}} \qquad (61)$$

In equation (**60**) when t passes through infinity, there is a discontinuity of $jC\pi$ in the integral and a discontinuity in Z of the slot width S. This enables us to determine the constant C. Performing this substitution and integrating, equation (**60**), we obtain,

$$Z = j\frac{S}{\pi} Ln\left(t + \sqrt{t^2-1}\right) = j\frac{S}{\pi}\cosh^{-1} t \qquad (62)$$

When, in particular, $t = a$, we have that $Z = +jg$; whence by substitution

$$a = \cosh\left(\frac{\pi g}{s}\right). \qquad (63)$$

The permeance is obtained directly from equation (**61**), for, by definition, the permeance is the ratio of ϕ_m to M; and these quantities are obtained by integrating equation (**61**) between the limits $t = -1$ and $t = +1$, and $t = +1$ and $t = +a$ respectively. Thus

$$P = \frac{\phi_m}{M} = \frac{2\int_0^1 dW}{\int_1^a dW} = 2\,\frac{K\ (1/a)}{K\ (\sqrt{1-(1/a)^2})} \tag{64}$$

By substituting the value for a in this last equation, the result given in Appendix I, equation (**37**) is obtained.

The leakage field shown in Fig. 21 can be adapted for mathematical treatment by drawing the line K–J prolonging the poles indefinitely in an axial direction. We will convert this case in a similar manner as the preceding, into first an infinite half plane, and then into a rectangle in the W plane. The point h corresponds to the point $t = -\infty$ in the t plane, c to the point $t = -a$, the point K to $t = -1$, J to the point $t = 0$, and f to $t = +\infty$. In the W plane the line h–C corresponds to the line $\phi = 0$, the line $C\ K\ J$ to the line $V = 0$, and the line J–f to the line $V = +M$. By Schwartz's theorem we have,

$$Z = C\int \frac{\sqrt{t+1}\ dt}{t\sqrt{t+a}} \tag{65}$$

$$W = C_2\int \frac{dt}{t\sqrt{t+a}} \tag{66}$$

The constant C in equation (**65**) and the constant a can both be determined from the discontinuities in the integral when $t = 0$ and when $t = \infty$, in a manner similar to the preceding case. This transformation was given in a different problem by C. H. Lees.[81] The result is that the constant $C = -jT/2\pi$ and $a = (T/K)^2$. Also,

$$z = +j\frac{T}{2\pi}\,Ln\left\{ \sqrt{t+1}\ \sqrt{t+(T/K)^2} + t + \frac{T^2+K^2}{2K^2}\right\}$$

$$-\frac{jK}{2\pi}\,Ln\left\{\frac{\sqrt{t+1}\ \sqrt{t+(T/K)^2} + (T/K)}{t} + \frac{T^2+K^2}{2\,TK}\right\} \tag{67}$$

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[81] *Phil. Mag., Loc. cit.*

If the flux passed directly between the pole $K\ J$ and the neutral plane, the permeance apparently in this region, say between the points $t = -1$ and $t = -e$, a small value, near zero, would be

$$P_{app} = \frac{2}{jK}\left[Z_{(t=-1)} - Z_{(t=-e)}\right]$$

$$= \frac{1}{\pi}\,Ln\left(\frac{4\,T^2}{(T^2-K^2)\,e}\right) - \frac{1}{\pi}\,Ln\left(\frac{T+K}{T-K}\right) \qquad \textbf{(68)}$$

On the other hand the constant C_2 is determined from equation (**66**) by the fact that there is a discontinuity in the integral of the amount $jC_2\ \sqrt{(1/a)}$ when t passes through zero, and W changes suddenly by the amount jM. The permeance of the leakage flux can be determined from equation (**66**); namely, when t changes from $-a$ to $-e$, the flux passing is the definite integral of equation (**66**) taken between these limits. Hence by substitution and integration

$$P = \frac{\phi_m}{M} = \frac{1}{\pi}\,Ln\left(\frac{4\,(T/K)^2}{e}\right) \qquad \textbf{(69)}$$

The value of the fringe permeance is the excess of the total permeance over the apparent permeance. Combining equations (**68**) and (**69**) and multiplying the permeance by four, we get the final result, which is given in Appendix I, equation (**47**). The factor four is to give the fringe permeance from all four corners of the pole.

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THE PHASE ANGLE OF CURRENT TRANSFORMERS

BY CHESTER L. DAWES

ABSTRACT OF PAPER

A method of testing the phase angle of current transformers by comparing readings obtained on a wattmeter whose current circuit is first connected to receive a part of the primary current (the remainder of the primary current passing in shunt through resistance) and then connected to the secondary circuit; the potential circuit is supplied from the primary voltage, and capacity or inductance is used to give the effect of a low power factor in the wattmeter. Corrections are applied for the error of phase of the part of the primary current which passes through the wattmeter, and separately for the error of phase in the primary caused by the fact that the primary current is not exactly in phase with the voltage used to supply the wattmeter. A second method of connection is suggested which avoids the latter correction, and other methods including the use of a three-phase circuit are discussed. Results of tests are given, and also check obtained by the use of an a-c. potentiometer. The method requires only portable instruments.

AT OR NEAR unity power factor, the phase difference between the primary and secondary currents of a current transformer has a negligible effect upon the accuracy of power measurements. When the power factor is as low as 0.7, however, this phase angle may introduce an appreciable error in such measurements. If in addition to the actual reading of the wattmeter, the true power and the power factor be known, there are sufficient data to determine this phase angle. Methods for obtaining and using the data just mentioned, are outlined in this paper. Further, it may be noted that by means of ordinary portable instruments, this angle may be measured with sufficient accuracy for practical work.

Referring to Fig. 1A, one phase of a three-phase alternator supplies current to an ammeter A_1, a bank of lamps, a second ammeter A_2, a wattmeter W, and the transformer to be tested, all in series.

In the first part of the measurements the transformer is not necessary, and may be either short-circuited or removed alto-

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Manuscript of this paper was received May 7, 1914.

gether. It is usually convenient to have it in circuit. In investigating this method a 10:1 portable transformer was used. In addition to the lamps in series with the ammeter and wattmeter, other lamps are necessary as a load on the generator, to insure constancy of its wave form, since later the generator load will be increased to the rated primary current of the transformer. If the capacity of the generator is not sufficiently great, its wave form may change, due to this increase of load. To prevent this change the extra lamps are left constantly in circuit.

To obtain the effect of a low power factor in the wattmeter and thus to intensify the effect of the transformer phase-angle, either an inductance coil or a condenser is connected in series with the potential coil of the wattmeter. It may be desirable to take observations first with one and then with the other, as a check. So far as the wattmeter is concerned, the condenser has the effect of a lagging current in the main circuit, and the inductance has the effect of a leading current. An air-core inductance is desirable, as the third harmonic current required by an iron core may introduce an error into the result. As an air-core coil of sufficient inductance and sufficiently low resistance may not always be available, the potential circuit of an induction type instrument is a very convenient substitute.

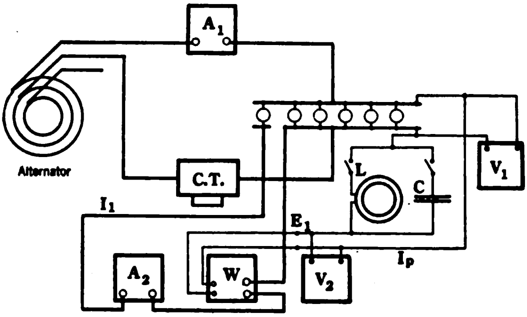

FIG. 1A

A voltmeter V_2 is connected across the potential terminals of the wattmeter. This voltmeter and the wattmeter are each rated at 75 volts in this particular case, though a lower rating is desirable. The ammeter A_1 is not absolutely necessary, but is useful in adjusting the load of the alternator if this be found desirable. Neither is the voltmeter V_1 absolutely necessary, but in conjunction with V_2 it gives a very convenient check on the frequency.

With the connections shown in Fig. 1A the current indicated by A_2 is adjusted to a value I_1, the desired secondary current of the transformer, and the voltage shown by V_1 is adjusted to some convenient value V_1 (120 volts in these particular tests).

The wattmeter reading W_1 will then be,

$$W_1 = E_1 I_1 \cos \theta \qquad (1)$$

where θ is the angle between the voltage V_1 and the current I_p in the potential circuit of the wattmeter (Fig. 2A; 2B).

V_1 = Voltage across lamps (Figs. 1A and 1B)
E_1, E_2 = Voltage across wattmeter, W, and voltmeter, V_2
I_1 = Current in A_2 and W (Fig. 1A)
I_2 = Current in transformer secondary (Fig. 1B)
I = Current in transformer primary (Fig. 1B)

The ammeter A_2 and the current coil of the wattmeter are now transferred to the secondary of the current transformer, the potential circuits remaining undisturbed (see Fig. 1B). The transformer primary current I is adjusted until A_2 reads I_2 the same value of current as before. The generator voltage is adjusted until the voltmeter V_2 gives a reading E_2, equal to E_1. The primary current is presumably still in phase with V_1, θ remains unchanged, the current passing through the wattmeter and the potential across its terminals are both the same as before. Therefore, any change in the wattmeter reading is apparently due to the phase displacement in the transformer.

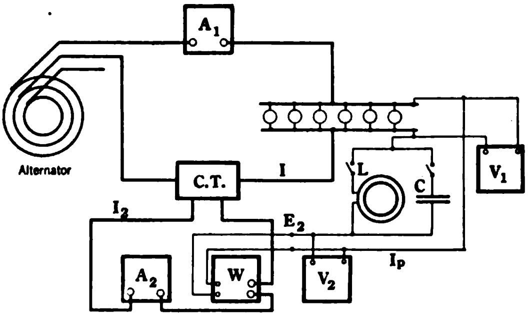

FIG. 1B

Let this angle of phase displacement be β and this last wattmeter reading be W_2. Then,

$$W_2 = E_2 I_2 \cos (\theta \pm \beta) = E_1 I_1 \cos (\theta \pm \beta) \qquad (2)$$

— I_2 usually leads I by the angle β.

Under these conditions the positive sign is taken when the inductance coil is used, and the negative sign when the condenser is used (See Figs. 2A, 2B). Also W_2 will ordinarily be less than W_1 if inductance is used in the wattmeter potential circuit, and greater than W_1 if capacity is used.

From equations (**1**) and (**2**)

$$\theta = \cos^{-1} \frac{W_1}{E_1 I_1} \tag{3}$$

$$(\theta \pm \beta) = \cos^{-1} \frac{W_2}{E_2 I_2} \tag{4}$$

from which β may be determined.

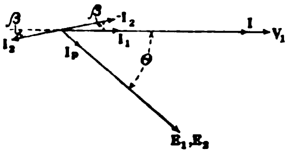

FIG. 2A

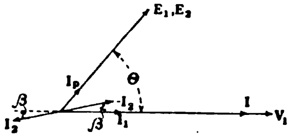

FIG. 2B

It is of course necessary that θ remain unchanged, hence the frequency must be the same in both cases. The ratio $\frac{V_1}{V_2}$ does not change with constant frequency, and hence may be used as a check of such constancy.

The preceding discussion assumes that the currents I_1 and I are in the same phase relation to V_1. This is true only when the inductance of the ammeter and the wattmeter current coil taken together is negligible compared with the resistance of the lamp bank. As the angle β is ordinarily much less than one degree, a very small inductance in these instruments will cause I_1 to lag behind V_1 by an angle sufficiently large to introduce a very appreciable error in the results.

In these experiments the ammeter and the wattmeter were of the well known P-3 type, having 5–10 ampere scales. The

10-ampere scale of the ammeter and the 5-ampere scale of the wattmeter were used in every case.

To determine the magnitude of the error due to their inductance, each one was measured by a *Drysdale d.c–a.c. potentiometer, and found to be as follows:

Inductance of ammeter current coil..... 5.5×10^{-5} henry
Inductance of wattmeter current coil....15.85×10^{-5} henry

These inductances together produce a lag angle of 12 minutes in the circuit containing these instruments, and as 12 minutes is nearly one-half the angle that is being determined, a correction must necessarily be made for it.

Referring to Figs. 3A and 3B, I_1 instead of being in phase with V_1, lags by an angle α.

Therefore, formula (**1**) must be changed to:

$$W_1 = E_1 I_1 \cos(\theta \pm \alpha) \qquad \textbf{(5)}$$

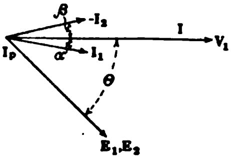

FIG. 3A

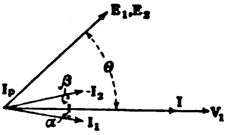

FIG. 3B

the negative sign being taken with inductance and the positive sign with capacity in the potential circuit of the wattmeter.

When the ammeter and wattmeter current coils are transferred to the transformer secondary,

$$W_2 = E_2 I_2 \cos(\theta \pm \beta) \text{ as before} \qquad \textbf{(6)}$$

The positive sign is used with inductance, and the negative sign with capacity in the potential circuit.

In either case, solving (**5**) and (**6**) simultaneously, the value of $\beta + \alpha$ may be found.

Another error may occur after connection is made to the transformer secondary. The primary current I is assumed in phase with the voltage V_1, but this is not exactly true. The current taken by the potential circuits of the two instruments, W and V_2, is out of phase with V_1 by the angle θ. Small as this current is, it may in virtue of its large phase angle introduce error as great as 40 per cent., if the primary current be in the neighborhood of 25 amperes. The error will be proportionately smaller with larger currents in the transformer primary. This angle will make the phase angle β apparently smaller than its actual value when inductance is used, and apparently larger when capacity is used. The angle β will be the mean of these two values, if the angle θ is the same when inductance is used as it is when capacity is used. In any event an exact correction can be easily made.

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*See paper "Measurement of Voltage and Current over a Long Artificial Power Transmission Line", by A. E. Kennelly and F. W. Lieberknecht. A. I. E. E. TRANS., Vol. XXXI (1912) p. 1131.

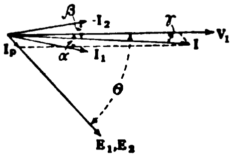

FIG. 4A

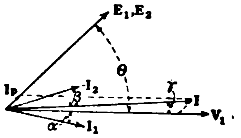

FIG. 4B

V_1 = Voltage across lamps. (See Figs. 1A and 1B)
E_1, E_2 = Voltage across wattmeter W and voltmeter V_2.
I_1 = Current in A_2 and W. (See Fig. 1A)
I_2 = Current in transformer secondary (Fig. 1B)
I = Current in transformer primary (See Fig. 1B)
I_p = Sum of potential currents in W and V_2.

Referring to Figs. 4A and 4B, showing the use of inductance and capacity, respectively,

$$W_1 = E_1 I_1 \cos(\theta \pm \alpha) \tag{7}$$

the negative sign is used with inductance and the positive with capacity,

$$W_2 = E_2 I_2 \cos(\theta - \gamma \pm \beta) \tag{8}$$

the positive sign is used with inductance and the negative with capacity.

Then,

$$\theta \pm \alpha = \cos^{-1} \frac{W_1}{E_1 I_1} \tag{9}$$

$$\theta - \gamma \pm \beta = \cos^{-1} \frac{W_2}{E_2 I_2} \tag{10}$$

from which $\beta + \alpha - \gamma$ can be determined, if inductance be used, and $\beta + \alpha + \gamma$ if capacity be used.

The angle γ is found as follows:

$$\sin \gamma = \frac{I_p \sin \theta}{I} \text{ (Figs. 4A, 4B)} \tag{11}$$

$$I_p = \frac{E_2}{r} \tag{12}$$

where θ is the angle between V_1 and the total current I_p in the potential circuits of V_2 and W: θ maybe determined from formula (**3**) with sufficient accuracy: r is the equivalent parallel resistance of the wattmeter and voltmeter potential circuits.

The correction for γ may be obviated by connecting one potential lead outside the current transformer, but dummy instruments, having constants equal to those of A_2 and the current coil of W_1, must be substituted in the current transformer secondary in order to maintain the same impedance drop through the transformer. This appears to be a rather doubtful expedient.

Below are given the results of tests made with a 10:1 portable current transformer.

Inductance (2.36 henrys)

Meters in Primary	V_1	E_1	I_1	W_1	$\cos(\theta-\alpha)$	$\theta-\alpha$
	120.0	34.25	5.00	87.5	0.5105	59° 18′
Meters in Secondary	V_1	E_2	I_2	W_2	$\cos(\theta-\gamma+\beta)$	$\theta-\gamma\times\beta$
	120.0	34.25	5.00	86.0	0.502	59° 52′

$\beta+\alpha-\gamma = 34'$
$\alpha = 12'$ (From inductance of instruments)
$\gamma = 7'$ (Formula 11)
$\beta = 29'$

Capacity (4.41 μf)*

Meters in Primary	V_1	E_1	I_1	W_1	$\cos(\theta+\alpha)$	$\theta+\alpha$
	120.0	53.2	5.00	116.5	0.4375	64° 3′
Meters in Secondary	V_1	E_2	I_2	W_2	$\cos(\theta-\beta-\gamma)$	$\theta-\beta-\gamma$
	120.0	53.2	5.00	120.0	0.4510	63° 12′

$\beta+\alpha+\gamma = 51'$
$\alpha = 12'$ (From inductance of instruments)
$\gamma = 11'$ (Formula 11)
$\beta = 28'$

*μf = microfarads

The inductance of the instrument current coils is not usually known, and its determination may require the use of apparatus not readily available. By using the connection shown in Fig. 5, β may be determined without a knowledge of the constants of the instrument current coils.

The potential circuit of the instruments is connected directly across the lamps in the instrument circuit so that the current in the potential circuit makes an angle θ rather than an angle $(\theta \pm \alpha)$ with the current passing through the lamps. The current in the potential circuit also passes through the current coils of the instruments, but knowing its value and phase angle, its effect on the meter readings can be readily determined.

Thus:

$$I_p = \frac{E_1}{r} \text{ formula } (\mathbf{12})$$

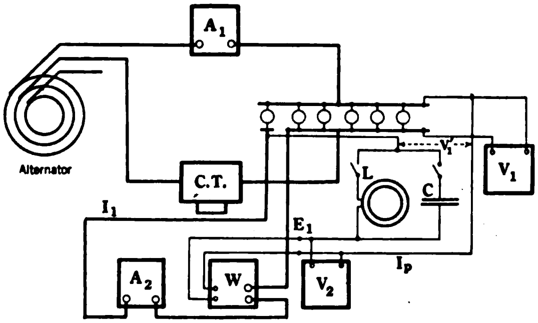

FIG. 5

The resistance of the potential coils is either marked on the instruments, or may be easily measured.

Referring to Fig. 6 A and 6B,

$$\cos \delta = \frac{W_1}{E_1 I_1} \tag{13}$$

I_1 is the current in the current coil of the wattmeter. Since I_p is usually small compared with I_1, δ may be found from (**13**) and as a first approximation, may be assumed equal to θ.

Then φ, Fig. 6A and 6B, is given by

$$\sin \varphi = \frac{I_p \sin \theta}{I_1} \tag{14}$$

Another trial for the value of φ may be necessary, but this method of trial and error is simpler than solving the figure trigonometrically.

V_1 = Voltage across lamp bank.
E_1, E_2 = Voltage across wattmeter W and voltmeter V_2
I_1 = Current in A_2 and W (Fig. 1A)
I_2 = Current in transformer secondary (Fig. 6A, 6B)
I = Current in transformer primary (Fig. 6A, 6B)
I_p = Sum of potential currents in W and V_2

The phase-angle of the transformer may then be determined as follows:

$$\cos\delta = \frac{W_1}{E_1 I_1} \text{ as in (3)} \tag{15}$$

$$\frac{W_2}{E_2 I_2} = \cos(\theta \pm \beta - \gamma) = \cos(\delta + \varphi \pm \beta - \gamma) \tag{16}$$

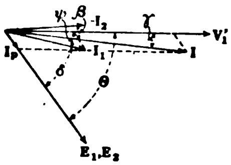

FIG. 6A

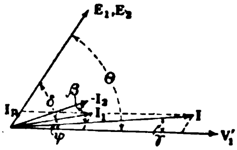

FIG. 6B

The upper sign is used with inductance and the lower ones with capacity in the potential circuit.

β may be found after having determined γ by formula (11).

Below are given the results obtained by the use of this method.

Inductance (2.53 henrys)

Meters in Primary	V_1	E_1	I_1	W_1	$\cos\delta$	δ	φ	$\delta+\varphi=\theta$
	120.0	31.2	5.0	84.0	0.5385	57°25′	1°1′	58°26′

Meters in Secondary	V_1	E_2	I_2	W_2	$\cos(\theta+\beta-\gamma)$	$\theta+\beta-\gamma$
	120.2	31.2	5.0	81.0	0.519	58°44′

$\beta-\gamma = 18'$
$\gamma = 6'$ formula (11)
$\therefore \beta = 24'$

Capacity (5.35μf)

Meters in Primary	V_1	E_1	I_1	W_1	cos δ	δ	φ	$\delta+\varphi=\theta$
	120.0	61.2	5.0	166.0	0.543	57°7′	2°3′	59°10′

Meters in Secondary	V_1	E_2	I_2	W_2	$\cos(\theta-\beta-\gamma)$	$(\theta-\beta-\gamma)$
	118.0	61.2	5.0	160.0	0.5225	58°30′

$\beta+\gamma = 40'$

$\gamma = 12'$ formula (11)

$\therefore \beta = 28'$

Capacity (4.41μf)

Meters in Primary	V_1	E_1	I_1	W_1	cos δ	δ	φ	$\delta+\varphi=\theta$
	120.0	53.1	5.0	125.0	0.471	61°54′	1°51′	63°45′

Meters in Secondary	V_1	E_2	I_2	W_2	$\cos(\theta-\beta-\gamma)$	$(\theta-\beta-\gamma)$
	119.2	53.1	5.0	120.0	0.453	63°4′

$\beta+\gamma = 41'$

$\gamma = 11'$

$\beta = 30'$

In each of the preceding cases, the low power factor in the wattmeter was obtained artificially by connecting either inductance or capacity in series with its potential circuit. As a three-phase generator is usually available, the low power factor may readily be obtained by connecting the lamp load and transformer across one phase of the generator and taking the potential from either of the other two. The potential, if taken from one phase, produces the effect of a lagging current, and if taken from the other phase produces the effect of a leading current. In either case, correction for the angle γ is obviated, since no low power factor potential circuit current passes through the transformer primary. The connections for this method of testing are shown in Figs. 7 and 8.

Extreme care must be exercised when this method is employed, as the results are dependent on duplicating the current and voltage relations in each of the two tests, first when the ammeter and wattmeter are in the primary circuit, and second when they are in the secondary circuit of the current transformer. The ammeter, A_1, and the voltmeter V_1 are now absolutely necessary, the former to keep the load the same in each case, and the latter as a check on the unbalancing of the generator voltages. In fact, a third voltmeter connected across the third phase is desirable to serve as a check on this unbalancing.

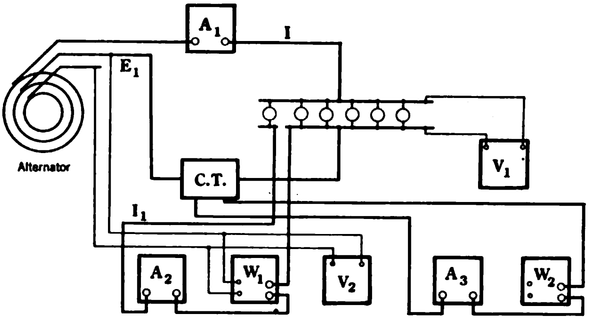

FIG. 7

In addition to duplicating the load, the circuit constants should remain unchanged in both cases (Figs. 7 and 8). Consequently two dummy instruments are employed, an ammeter A_3, similar to A_2, and a wattmeter W_2, similar to W_1. When A_2 and W_1 are in the primary circuit, these two dummies are connected in the

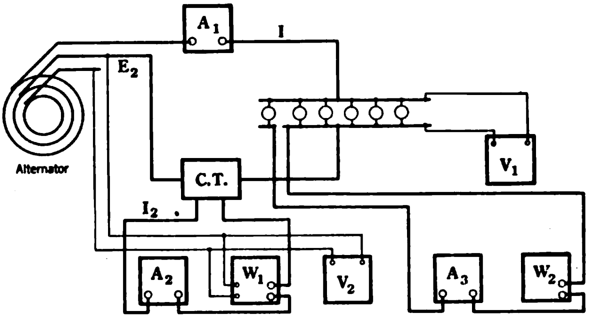

FIG. 8

secondary circuit of the transformer (Fig. 7). When it is necessary to change A_2 and W_1 to the transformer secondary, their places in the primary are taken by the dummies (Fig. 8). The voltmeter V_1 should have a high ratio of resistance to inductance, as a very small lagging current may introduce an appreciable error in the results, equivalent to the error introduced by the angle γ.

If the generator be so large that its voltages remain balanced under the load, power-factors of 50 per cent, either lag or lead are obtained. With a 12-kv-a., 120-volt alternator, the writer obtained power factors of 61 per cent. and 32 per cent respectively.

The advantages of this method over those stated earlier in the paper are that neither inductance nor capacity is necessary, no correction for the angle γ needs to be made, and a slight change of frequency does not introduce an appreciable error. On the other hand, more careful adjustment of the load is essential, and more instruments are necessary.

Below are given the results of tests in which this method was utilized.

Current Lagging

Meters in Primary	V_1	E_1	W_1	I_1	$\cos(\theta-\alpha)$	$\theta-\alpha$
	120.0	140.2	426.0	5.0	0.608	52°33′
Meters in Secondary	V_1	E_2	W_2	I_2	$\cos(\theta+\beta)$	$\theta+\beta$
	120.0	140.2	420.0	5.0	0.599	53°12′

$\beta+\alpha = 39'$
$\alpha = 12'$ (from inductance of instruments)
$\therefore \beta = 27'$

Current Leading

Meters in Primary	V_1	E_1	W_1	I_1	$\cos(\theta+\alpha)$	$\theta+\alpha$
	120.0	118.8	188.0	5.0	0.3165	71°33′
Meters in Secondary	V_1	E_2	W_2	I_2	$\cos(\theta-\beta)$	$\theta-\beta$
	120.0	118.8	194.4	5.0	0.327	70°55′

$\beta+\alpha = 38'$
$\alpha = 12'$ (from inductance of instruments)
$\therefore \beta = 26'$

In all these experiments the wave forms of the voltages and the currents in the primary and in the secondary of the transformer, and of the current taken by the potential circuits were investigated with an oscillograph, and no radical departure from a sine wave was observed.

These methods of determining phase angle are not advocated where a high degree of precision is desired. The results are dependent upon the difference of two nearly equal quantities, and a slight error in one observation introduces a much greater percentage error into their difference. On the other hand, the methods involve only portable instruments; ordinary errors in the ammeter and voltmeter do not affect the results; and the wattmeter reading changes so slightly, that it is a question if the instrument need be calibrated. Furthermore the measurements can be made without introducing additional resistance into the transformer secondary. If the adjustments and observations are carefully made, the degree of accuracy obtainable is sufficient for most practical purposes. In fact, when power corrections for phase displacement are being made, it is not necessary to know the angle to a high degree of accuracy.

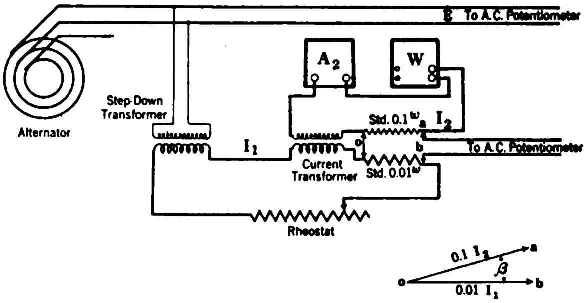

FIG. 9

To check the results obtained by the previous methods the phase angle of the transformer was measured with the Drysdale a-c. potentiometer. The diagram of connections is shown in Fig. 9.

The voltages across the resistances *oa* and *ob* were first measured. As the potentiometer necessarily measures their phase relations to the voltage *E*, it would seem that the phase angle could be determined directly from these two readings. But the smallest division on the angle scale, corresponding to one degree, is about one millimeter, and hence the measured value of the phase angle would depend entirely upon the accuracy of estimating tenths. Consequently, the voltage across the open ends, *ab*, was also measured. These results are shown vectorially in Fig. 10. Solving the triangle of voltages and correcting for the lag angle of the standard resistances, the angle β is found to be 28′, which closely checks previous results.

Incidentally, the ratio of transformation found to be from these data is $\frac{49.89}{5.008} = 9.962$

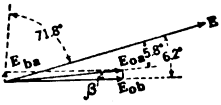

FIG. 10

In closing the writer wishes to thank Prof. H. E. Clifford of Harvard University, and Prof. F. A. Laws of the Massachusetts Institute of Technology for helpful criticisms and suggestions.

Presented at the Portland Section meeting of the American Instiiue of Electrical Engineers, Portland, Ore., January 5, 1915.

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THE MULTIPLEX COST AND RATE SYSTEM

BY OTTO B. GOLDMAN

ABSTRACT OF PAPER

The author gives the method of determining the cost of service having a variable demand, with special application to electric service, because the cost does and must always determine the selling price; competition and commissioners can only regulate the profit therein contained. Competition is destructive, involving an immense amount of unnecessary expenditure and lost motion. In order to insure the lowest price to the consumer we must have regulation, and monopoly. The author starts with the premise that an equipment must earn its cost and profits when in use; certainly it cannot do so when idle. The greater the percentage of total time an equipment or part thereof stands idle, the more it must earn when in use, because interest, etc. runs continuously. The subject is a big one and of tremendous import not only to the electric business, but to all business, and it has been the center of discussion for many years. It is now time to get down to absolute proofs of every conclusion, based upon fundamental facts.

THE SUBJECT of rates has received much attention of late due naturally to its importance, and consequently many "systems" more or less related have been devised. A system is simply an attempt to straight-jacket judgment and make it all good. It must be correct or it is worse than none, and in order to be so, there must appear in the derivations no unbased assumption, such as are so often found. It must be apparent at once that no rate system can really be devised until a cost system has been obtained. For cost governs price, competition—and railroad commissions—only the profit therein contained. The multiplex cost system is a means of determining the cost of a variable service such as power service, gas, transportation etc, etc. In presenting this, I wish to acknowledge my indebtedness to the ability and patience of Mr. F. D. Weber, for valuable assistance. We are presenting the following only in its application to electric power service.

The demand for electric power service varies greatly during the day, from a very light night load, a tolerable day load, to an excessive peak load. Besides this we have seasonal variations

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Manuscript of this paper was received Nov. 30, 1914.

of load. That must mean that part of our equipment is idle or only partly used during the day and year. We have here assumed that an equipment must pay for itself when in use—certainly it cannot do so when idle. As usual, we consider our costs as divided into two parts (1) fixed charges, being all costs pertaining to an equipment when standing idle and (2) operating costs being all additional costs. It is evident that the first are continuous, the latter intermittent, depending on use. But the entire or total fixed charges for the year must be paid for during those hours in the year that the equipment is in use. Thus if F are the fixed charges per year of a given equipment and N the number of hours in the year that the equipment is used, then F/N is the fixed charge cost per hour. This becomes $F/24 \times 365$ only when the plant is in continuous use.

DAILY VARIATIONS

In actual power service, we have primarily to consider the load variations during the day. In treating this variation, we consider the day divided into a number of periods. The greater the number of periods the more exact our results may be made but the more intricate. Where we have two periods, we have the duplex system; where three, the triplex etc. The latter we will now treat, calling the three periods the night, day and peak periods. Let us call M_1 the maximum demand during the night period, K_1 the mean demand, and N_1 the duration. in hours of the night period; similarly M_2 K_2 and N_2 for the day period and M_3 K_3 and N_3 for the peak period, where $N_1 + N_2 + N_3 = 24$. We consider the total number of customers as divided into three classes according to the periods in which they demand service, charging each class with the cost burden that they place on the equipment, excepting as modified by the relation of one period to the others. In the above the night customers need an equipment of size M_1, the day customers one of size M_2 and the peak customers one of size M_3. Since $M_1 < M_2 < M_3$, the equipment of size M_1 is needed throughout the 24 hours, that of size $M_2 - M_1$ for $N_2 + N_3$ hours and that of size $M_3 - M_2$ for N_3 hours. For the present we will assume that the conditions assumed above are the same for each day of the year. Later we will consider seasonal variations.

Let us call C the cost of equipment per kw. and P the per cent of fixed charges, per year, so that CP becomes the fixed charge cost per kw-year. For the night period size we have M_1 CP as the total annual fixed charges and since this part of the equipment is in use 24 hours per day the fixed charge cost per hour becomes $M_1CP/365 \times 24$ or $M_1CP/365 \times 24\ K_1$ per kw-hr. so that we have, for the fixed charge cost per hour

$$R'_1 = \frac{M_1CP}{365 \times 24 \times K_1} = \frac{M_1CP}{365 \times (N_1 + N_2 + N_3)\, K_1} \tag{1}$$

During the day period we have for the total fixed charge cost per hour

$$\frac{M_1CP}{365\,(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)\, CP}{365\,(N_2 + N_3)}$$

Dividing this by the mean load during this period we get

$$R'_2 = \frac{CP}{365\, K_2}\left[\frac{M_1}{(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)}{(N_2 + N_3)}\right] \tag{2}$$

which is the fixed charge cost for this period. During the peak period we have for the total cost per hour

$$\frac{M_1CP}{365\,(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)\, CP}{365\,(N_2 + N_3)} + \frac{(N_3 - M_2)\, CP}{365\, N_3}$$

whence the fixed charge cost per kw-hr. becomes

$$R'_3 = \frac{CP}{365\, K_3}\left[\frac{M_1}{(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)}{(N_2 + N_3)} + \frac{(M_3 - M_2)}{N_3}\right] \tag{3}$$

If now we call O_1 the operating cost per hour during the night period, O_2 and O_3 those during the day and peak periods respectively, then our costs (total) per kw-hr. become for the night, day and peak respectively.

$$R_1 = \frac{CP}{365\, K_1}\left[\frac{M_1}{(N_1 + N_2 + N_3)}\right] + \left[\frac{O_1}{K_1}\right] \tag{4}$$

$$R_2 = \frac{CP}{365\, K_2}\left[\frac{M_1}{(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)}{N_2 + N_3}\right] + \frac{O_2}{K_2} \tag{5}$$

$$R_3 = \frac{CP}{365\,K_3}\left[\frac{M_1}{(N_1+N_2+N_3)} + \frac{(M_2-M_1)}{(N_2+N_3)} + \frac{(M_3-M_2)}{N_3}\right] + \frac{O_3}{K_3} \qquad (6)$$

This is, as stated above, on the basis of continuous use at the rates stated throughout the year.

SEASONAL VARIATIONS

Taking into consideration the variations of load during the year we will usually find a comparatively light summer load, a medium spring and fall load and a very heavy winter load. That means that not only must part of our plant be idle part of each day, but that part of our equipment must lie idle often for months at a time due to the above mentioned conditions. Again, as above, in the daily load variations, the aggregate of those customers causing any special burdens on the equipment must pay for the burden they create by their demand. To determine this, we proceed as follows. Consider the year as divided into, say, three periods, the minimum of D_1 days duration, the mean of D_2 days duration, and the maximum of D_3 days duration. As above, let use call M_1, M_2 and M_3, the maximum demands for the night, day and peak periods respectively of the first or minimum period of the year, similarily K_1, K_2, and K_3, the mean demands in kw. and N_1, N_2, and N_3, the lengths in hours of the night, day and peak periods, where $D_1 + D_2 + D_3 = 365$. Then for this minimum period, the equations (**4**), (**5**) and (**6**) again hold.

For the mean period, let us call

M_1', M_2', and M_3', the maximum demands
K_1', K_2', and K_3', the mean demands
N_1, N_2, and N_3, the length in hours and
O_1', O_2', and O_3' the operating cost per hour of the night, day and peak periods respectively. Then during the night period we have for the cost per hour

$$\frac{M_1CP}{(D_1+D_2+D_3)\,(N_1+N_2+N_3)} + \frac{M_1'-M_1}{(D_2+D_3)\,(N_1+N_2+N_3)} + O_1'$$

whence the cost per kw-hr. is

$$R_1' = \frac{CP}{(N_1 + N_2 + N_3)\,K_1'}\left[\frac{M_1}{D_1 + D_2 + D_3} + \frac{M_1' - M_1}{D_2 + D_3}\right] + \frac{O_1'}{K_1'} \qquad (7)$$

During the day period, we have for the cost per hour

$$\frac{M_1 CP}{(D_1 + D_2 + D_3)\,(N_1 + N_2 + N_3)} + \frac{(M_1' - M_1)\,CP}{(D_2 + D_3)\,(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)\,CP}{(D_1 + D_2 + D_3)\,(N_2 + N_3)} + \frac{M_2' - M_2\,CP}{(D_2 + D_3)\,(N_2 + N_2)} + O_2'$$

whence the cost per kw-hr. becomes

$$R_2' = \frac{CP}{K_2'}\left\{\frac{1}{(N_1 + N_2 + N_3)}\left[\frac{M_1}{D_1 + D_2 + D_3} + \frac{M_1' - M_1}{D_2 + D_3}\right] + \frac{1}{(N_2 + N_3)}\left[\frac{M_2 - M_1}{D_1 + D_2 + D_3} + \frac{M_2' - M_2}{D_2 + D_3}\right]\right\} + \frac{O_2'}{K_2} \qquad (8)$$

During the peak period, we have for the cost per hour

$$\frac{M_1 CP}{(D_1 + D_2 + D_3)\,(N_1 + N_2 + N_3)} + \frac{(M_2 - M_1)\,CP}{(D_1 + D_2 + D_3)\,(N_2 + N_3)} + \frac{(M_3 - M_2)\,CP}{(D_1 + D_2 + D_3)\,N_3} + \frac{(M_1' - M_1)\,CP}{(D_2 + D_3)\,(N_1 + N_2 + N_3)} + \frac{(M_2' - M_2)\,CP}{(D_2 + D_3)\,(N_2 + N_3)} + \frac{(M_3' - M_3)\,CP}{(D_2 + D_3)\,N_3} + O_3'$$

Dividing this by the mean load, we get

$$R_3' = \frac{CP}{K_3'} \left\{ \frac{1}{(N_1 + N_2 + N_3)} \left[\frac{M_1}{(D_1 + D_2 + D_3)} + \frac{(M_1' - M_1)}{(D_2 + D_3)} \right] + \frac{1}{(N_2 + N_3)} \left[\frac{M_2 - M_1}{D_1 + D_2 + D_3} + \frac{M_2' - M_2}{D_2 + D_3} \right] + \frac{1}{N_3} \left[\frac{M_3 - M_2}{D_1 + D_2 + D_3} + \frac{M_3' - M_3}{D_2 + D_3} \right] \right\} + \frac{O_3'}{K_3'} \qquad (9)$$

For the maximum period let us call

M_1'', M_2'', and M_3'', the maximum demands
K_1'', K_2'', and K_3'', the mean demands
N_1, N_2, and N_3, the length in hours and
O_1'', O_2'' and O_3'', the operating costs per hour of the night day and peak periods respectively of this maximum period. Then during the night period of this season, we have for the cost per hour,

$$\frac{M_1 CP}{(N_1 + N_2 + N_3)\,(D_1 + D_2 + D_3)} + \frac{M_1' - M_1}{(N_1 + N_2 + N_3)\,(D_2 + D_3)} + \frac{M_1'' - M_1'}{(N_1 + N_2 + N_3)\,D_3} + O_1''$$

Whence the cost per kw-hr. is

$$R_1'' = \frac{CP}{(N_1 + N_2 + N_3)\,K_1''} \left[\frac{M_1}{(D_1 + D_2 + D_3)} + \frac{(M_1' - M_1)}{(D_2 + D_3)} + \frac{M_1'' - M_1'}{D_3} \right] + \frac{O_1''}{K_1''} \qquad (10)$$

Similarly we get for the cost per kw-hr. during the day period,

$$\begin{aligned} R_2'' = \frac{CP}{K_2''} \Bigg\{ & \frac{1}{(N_1 + N_2 + N_3)} \left[\frac{M_1}{D_1 + D_2 + D_3} + \frac{M_1' - M_1}{D_2 + D_3} \right. \\ & \left. + \frac{M_1'' - M_1'}{D_3} \right] + \frac{1}{(N_2 + N_3)} \left[\frac{(M_2 - M_1)}{(D_1 + D_2 + D_3)} \right. \\ & \left. + \frac{M_2' - M_2}{(D_2 + D_3)} + \frac{M_3'' - M_2'}{D_3} \right] \Bigg\} + \frac{O_2''}{K_2''} \end{aligned}$$

and for the peak period

$$\begin{aligned} R_3'' = \frac{CP}{K_3''} \Bigg\{ & \frac{1}{(N_1 + N_2 + N_3} \left[\frac{M_1}{(D_1 + D_2 + D_3)} + \frac{(M_1' - M_1)}{(D_2 + D_3)} \right. \\ & \left. + \frac{M_1'' - M_1'}{D_3} \right] + \frac{1}{(N_2 + N_3)} \left[\frac{(M_2 - M_1}{(D_1 + D_2 + D_3)} \right. \\ & \left. + \frac{(M_2' - M_2)}{(D_2 + D_3)} + \frac{(M_2'' - M_2')}{D_2} \right] + \frac{1}{N_3} \left[\frac{M_3 - M_2}{(D_1 + D_2 + D_3)} \right. \\ & \left. + \frac{(M_3' - M_3)}{(D_2 + D_3)} + \frac{M_3'' - M_3'}{D_3} \right] \Bigg\} + \frac{O_3''}{K_3''} \end{aligned}$$

For brevity's sake we are leaving out for the present, the case of more than three periods in the year and the rather important condition where in each of the seasonal periods, the corresponding periods of the day are different, *i. e.* where we have for the length of the night, day and peak periods, N_1, N_2 and N_3, during the minimum period, $N_1,'$ N_2' and N_3', during the mean period and N_1'', N_2'' and N_3'', during the maximum period. We will instead proceed at once to show the application of a concrete example under the first case. This application is merely illustrative.

APPLICATION OF CASE I

In computing the cost of power in the following, we have segregated each factor contributing thereto; *i. e.* generation, transmission, transformation, and distribution. This must be done in every practical example, as it usually happens that we have customers taking power directly at the power house, or along the transmission line, who naturally would not be chargeable for that part or parts of our entire equipment that is not needed to serve them. Let us assume then that we have at the generating plant the following conditions:

4000 kw. maximum demand in the night period
13000 " " " " " day "
20000 " " " " " peak "
4000 kw. mean demand night period
10000 " " " day "
18000 " " " peak "

7 hours duration of night period
11 " " " day "
6 " " " peak "

So also cost of generating plant and step up transformers per kw. of capacity $150.00, and per cent of fixed charges (annual) 13 per cent. Then our fixed charges are

$$150 \times 13\% = \$19.50 \text{ per kw-year} \qquad \text{or,}$$
$$19.50/365 = \$.0534 \text{ per kw-day}$$

Reasonable consideration must be taken of the future, so that a growth factor must be allowed, because increases must be made in reasonable size units. What a reasonable growth factor is can only be determined in each individual case. In any plant under consideration, that growth factor actually existing should be allowed unless it is apparently unreasonable. Let us assume that this growth factor in our case is 20 per cent., then we have for our fixed charges $0.06408 per kw-day, which becomes 0.06408/24 or $.00267 per kw-hr. for the night period

During the day period we have for our cost per hour

$$(4000 \times \$0.00267 + 13000 - 4000) \times \$0.06408/17 \text{ or } \$44.61$$

The mean load being 10000 kw., we get for the fixed charges

$$44.61/10000 \text{ or } \$0.004461 \text{ per kw-hr.}$$

During the peak period, we have for the cost per hour

$$20000 - 13000 \times 0.06408/6 + 9000 \times 0.00377 + 4000 \times 0.00267 \text{ or } \$119.37$$

Since our mean load is 18000 kw. we get for our fixed charges 119.37/18000 or $0.00663 per kw-hr.

If our operating costs are

$0.00020 for the night period, per kw-hr.
0.00014 " " day " " " and
0.00011 " " peak " " "

then our total production cost per kw-hr. becomes

0.0002 + 0.00267 = 0.00287 for the night period
0.00014 + 0.004461 = 0.004601 for the day period
0.00011 + 0.00663 = 0.00674 for the peak period.

For the transmission line we will assume a cost of 25 cents per kw-mile with a fixed charge cost of 15 per cent, and 50 miles of transmission to the first substation. Then the fixed charge cost per kw-mile-year is 0.25 × 0.15 = 0.0375 and per day is

0.0375 / 365 = 0.000103 which becomes for the total 50 miles after allowing for the growth factor as before

(0.000103 × 50) 1.20 = 0.00618 per kw-day.

For the night period then we have

0.00618/24 = 0.000258 the fixed charge cost per kw-hr.

During the day period, we have the cost per kw-hr. for the added equipment. The added equipment is

13000 – 4000 = 9000 kw. whence the cost per hour is
9000 × 0.000363 = $3.267 +
4000 × 0.000258 = $1.032

or a total of $4.299. Whence the fixed charge cost per kw-hr. is

4.299/10000 = $0.0004299

During the peak period, we have for the added equipment the fixed charge cost per kw-hr. of 0.00618/6, or 0.00103. The added equipment is

20000 – 13000 = 7000 kw. whence we have
7000 × 0.00103 = $7.21 +
9000 × 0.000363 = 3.267 +
4000 × 0.000258 = 1.032 or a total of $11.509

Whence the fixed charge cost per kw-hr. is

11.509/18000 or $0.0006394

Taking for the operating costs per kw-hr. the following:

$0.00002778 during the night
0.00001667 during the day and
0.00001125 during the peak, we get for the total transmission costs; per kw-hr.:

0.000258 + 0.00002778 or $0.00028578 for the night
0.00001667 + 0.0004299 or $0.00044657 for the day
0.00001125 + 0.0006394 or $0.00065065 for the peak period.

We now come to the substation No. 1. Suppose here we have for maximum demands

1000 kw. during the night period
2000 " " " day " and
4000 " " " peak " and for the mean demand
900 " " " night
1500 " " " day and,
3600 " " " peak period

The length of each period, being taken as before, while the cost or investment per kw. at the substation is taken at **$15.00** and the per cent of fixed charges per year is taken at 10, then the fixed charge cost per kw-year is 15.00 × 10 per cent. or **$1.50**, while the fixed charge cost per kw-day becomes, after allowing for growth factor as before

(1.50/365) 1.20 or $0.00492

For the night we have for the cost per kw-hr.

(0.00492/1000)/(24 × 900) or $0.000228

For the day period we have for the fixed charge cost per hour

(2000 − 1000) × 0.00492/17 or $0.29
1000 × 0.000205 or 0.205 or a total of $0.495 *i. e.*
0.495/1500 or $0.00033 per kw-hr.

During the peak period, we have for the fixed charge cost per hour,

(4000 − 2000) × 0.00492/6 or $1.64
1000 × 0.00029 or $0.29
1000 × 0.000205 or $0.205 or a total of $2.135

Whence the cost per kw-hr. becomes

2.135/3600 or $0.000593

If our operating costs at the station are

0.00067 per kw-hr. during the night
0.000417 per kw-hr. during the day and
0.00028 per kw-hr. during the peak period,

then we have for our total substation costs

0.00067 + 0.000228 = $0.000898 per kw-hr. night period
0.000417 + 0.00033 = 0.000747 " " (day period)
0.00028 + 0.000593 = 0.000873 " " (peak period)

Summarizing to substation No. 1, we have:
during the night period

Generating cost per kw-hr. is $0.00287
Transmission " " " " 0.0002858
Substation " " " " 0.000898
Total 0.0040538

which at 95 per cent efficiency becomes $0.00416 per kw-hr.
During the day period, we have

Generating cost per kw-hr. are $0.0046
Transmission " " " " 0.0004467
Substation " " " " 0.000747
Total $0.005793, which at 95 per cent

efficiency becomes $0.0061 per kw-hr.
During the peak period, we have

Generating cost per kw-hr. is $0.00674
Transmission " " " " 0.00065065
Substation " " " " 0.000873
Total $0.00826365

which at 95 per cent efficiency becomes $0.0087 per kw-hr.

If the distance from substation No. 1 to substation No. 2 is 50 miles, that will make our total distance from the generating plant to substation No. 2 100 miles, so that, other conditions being assumed equal, our transmission costs to substation No. 2 will be double that to substation No. 1 or

$0.000572 per kw-hr. for the night period
0.000892 " " " " day "
0.0013 " " " " peak "

At substation No. 2 we have for the maximum demands

3000 kw. during the night
11000 kw. during the day and
16000 kw. during the peak period

mean demands

3000 kw. during the night
8500 kw. during the day and
14400 kw. during the peak period.

Investment $11.00 per kw. of capacity
Fixed charges 10 per cent
11.00 × 10 per cent = $1.10 fixed charge cost per kw-yr. or
1.10/365 0.003 per kw-day, which allowing 20 per cent growth factor, gives $0.0036 per kw-day total.

Whence for the night period we have

0.0036/24 or $0.00015 per kw-hr.

During the day period we have

(11000 − 3000) × 0.0036/17 = 1.69 and
3000 × 0.00015 = 0.45

or a total of $2.05, whence

2.05/8500 = 0.00025 fixed charge per kw-hr.

During the peak period, we have

(16000 − 11000) 0.0036/6 = $3.00
8000 × 0.00021 = $1.69
3000 × 0.00015 = $0.45
Total $5.14

Whence the fixed charge cost per kw-hr. becomes

5.14/14400 or $0.000357

If the operating costs are

0.000263 per kw-hr. during the night
0.000194 per kw-hr. during the day and
0.000162 per kw-hr. during the peak

then our total costs at substation No. 2 per kw-hr. become

0.000263 + 0.00015 = 0.000413 for the night
0.000194 + 0.000252 = 0.000446 for the day and
0.000162 + 0.0003275 = 0.0004895 for the peak period.

The total costs to and including substation No. 2 then become for the night period

Generation	0.00287
Transmission	0.000572
Substation No. 2	0.000413
Total	0.003855

If the efficiency to and including substation No. 2 is 90 per cent this total becomes 0.004283 for the available power.

For the day period,

Generation	0.00461
Transmission	0.000892
Substation No. 2	0.000446
Total	0.005948

which at 90 per cent efficiency again becomes 0.006610.

For the peak period,

Generation	0.00674
Transmission	0.0013
Substation No. 2	0.0004895
Total	0.00853

which at 90 per cent efficiency becomes $0.00948

Distribution No. 1 for Service from Substation No. 1

We have now to get the cost of our distribution system per kw-hr. Suppose here we have an investment of $100.00 per kw. and that the per cent of fixed charges is 12, then is

100.00 × 12 per cent or $12.00 the fixed charge cost per kw. per year,

or 12.00/365 = 0.33 the fixed charge cost per kw. per day,

and allowing 20 per cent for growth factor as before, our fixed charges per kw. per day becomes $0.0396.

For the night then we have

0.0396/24 = 0.00165

(0.00165 × 1000)/900 = 0.00183 fixed charge cost per kw-hr.

During the day we have

(2000 − 1000) × 0.0396/17 = 2.33
0.00183 × 1000 = 1.83
Total............4.16
4.16/1500 = $0.002774 per kw-hr.

During the peak period we have

(4000 − 2000) (0.0396)/6 = $13.20
1000 × 0.00233 = 2.33
1000 × 0.00183 = 1.83
Total..............$17.36
17.36/3600 = $0.00482 per kw-hr.

Assuming then that the operating costs per kw-hr. are

0.00049 during the night
0.00043 " " day and
0.00038 " " peak period

then our total costs per kw-hr. become

0.00049 + 0.00183 = 0.00232 during the night
0.00043 + 0.002774 = 0.0032 during the day
0.00038 + 0.00482 = 0.0052 during the peak period.

If the efficiency of our distribution system is 90 per cent, then the above become for the total cost per kw-hr. of available power,

$0.0026 for the night period
0.00356 for the day period and
0.00578 for the peak period

The cost of the power to and including distribution per kw-hr. then is

0.0043 + 0.0026 = $0.0069 for the night period
0.0061 + 0.00356 = 0.00966 for the day period.
0.00863 + 0.00578 = 0.01441 for the peak period.

DISTRIBUTION NO. 2

From substation No. 2 we have distribution system No. 2. Suppose that the investment per kw. of capacity here is **$90.00** and that the per cent of fixed charges is 11, then the fixed charges per kw-year are 90.00 × 11 per cent or $9.90 or $0.0271 per kw-day. Allowing again 20 per cent for growth factor, this becomes 0.0325.

For the night period then we have

0.0325/24 = 0.00135 fixed charges per kw-hr.

For the day period, we have

(11000 – 3000) × 0.0325/17 $15.20
3000 × 0.00135................ 4.05
Total.............. 19.25
19.25/8500 = 0.00226 per kw-hr.

For the peak period we have

(16000 – 11000) × 0.0325/6 = $27.00
8000 × 0.0019.............. = 15.20
3000 × 0.00135............. = 4.05
Total.............. $46.25
46.25/14400 = 0.0029 per kw-hr.

If the operation costs per kw-hr. are

0.000375 during the night
0.000325 during the day and
0.0003 during the peak period

then the total costs for distribution under system No. 2 are,

0.000375 + 0.00135 = 0.001725 for the night.
0.000325 + 0.00226 = 0.002585 for the day
0.0003 + 0.0029 = 0.0032 for the peak period.

At 90 per cent efficiency of our distribution system, these become,

0.001917 for the night
0.00287 for the day
0.003555 for the peak period based on available power.

The total costs to and including distribution system No. 2 are

0.004283 + 0.001917 = 0.0062 for the night
0.00661 + 0.00287 = 0.00948 for the day
0.003555 + 0.00948 = 0.13 for the peak period.

THE MULTIPLEX RATE

Having determined the cost of service, we have now to determine the rate. In order that a rate be of practical use, it must be fairly simple, and in effect such that it redounds to the best interest of both the consumers and the power company. Let us first take up the matter of simplicity. In applying this rate, we add to the previously determined cost of service a certain percentage of allowable profit which should depend on the efficiency of the system. In order then to apply the multiplex rate it seems that a time-wattmeter would be necessary for each installation, and this would be impracticable. But this is not at all necessary. The vast majority of small power users are residential light customers. The time when and the number of hours that they demand service, are practically identical one with another. A test will show what per cent of their load is in each period, and knowing this we can at once calculate a flat rate per kw-hr., or per lamp, as we choose, based not on guess work but on knowledge of the cost of that service and what that service consists of. So we can classify and give a flat rate to any service, as residential lighting, commercial, or street lighting etc. that allows itself of group classification. In these cases we would actually simplify the rate, *i. e.* for any given season, although we would have to vary the rate in each season to take care of the variation of the cost of service in the different periods of the year. In the remaining cases that do not allow of group classification, we would have to resort to time-wattmeters or agreements restricting usage without special permit. These would be mostly the larger power users.

In giving a rate based on cost of service, we are treating each and every customer impartially and are therefor creating a feeling of mutuality between the power company and the customers. That is a valuable asset. Not only that, but a rate based on cost automatically tends to discourage the use of power at such a time that it would tend to increase the average cost. It would tend to encourage the use of power at such a time that the average cost be reduced *i. e.* the demand would gravitate as much as physically possible to the time of lowest cost. This means that the valleys in the load curve will tend to fill up. Growth will be along natural, healthy lines, instead of artificial.

In an excellent resume on rates, Mr. Stacy Hamilton presented before the Northwest Electric Light and Power Association at its joint meeting with the Pacific Coast meeting of the A. I. E. E. Spokane, Wash., September 9-11, 1914, a paper which not only aptly illustrates present day rates but present day incongruities—and some of these unwittingly. He states, for example, "There are two general basic theories on which a system of rates may be established, *i. e.* the cost of service theory, and the value of service theory." He says further: "Under the cost of service theory we have, at one extreme, the attempt to differentiate in proportion to the exact cost to each individual condition of service. This must necessarily result in a schedule so complicated as to be entirely impracticable. At the other extreme we have a general average or uniform rate to all customers based on the general average cost of rendering service to all consumers." As a matter of fact there are at present neither rates based on the cost of service nor on the value of service. Before we can have a rate based on cost of service, we must know definitely the cost of service; before we can have a rate based on the value of service, we must definitely know the value of the service in each individual or group case. The value of a service is not what it costs but the profit it earns. For example, we may be manufacturing a certain article. Suppose that wages increase and at the same time the selling price of the article decreases. Then it is evident that the cost of the service has increased at the same time that the value of the service has decreased. So that before we could make a rate based on value of service, we would have to know in detail our customers business. Such a rate would have to decrease in times of business depression and increase in good times. Under such a rate the value of service may decrease while the cost of service remains stationary or even increases. Such a rate does not exist nor ever will exist, for the reason that the fundamental basis of any charge must always be the cost; competition and commissions can only regulate the profits, to which the latter may add by way of regulation the proper distribution of the costs to individual or group cases.

Respecting rates based on cost of service, we have said that such does not exist, nor can they exist until the cost of service has been determined as is first done in this article. We have shown above that the application of a rate based on cost in the multiplex form, used with good judgment is not any more complicated on the average than present rates. The so-called uniform rate is not based on the cost but only on average (annual) cost. Such rates cannot be in proportion to costs. An assumption that they are so would involve errors of over 100 per cent; that is absolutely valueless results. Power service is a natural monopoly, *i. e.* this service can be rendered better and cheaper under such conditions than under competition. Competition then becomes a farce at the expense of the public. But having a monopoly, a distinction between "competitive" and "noncompetitive business" becomes discrimination. Present rates are based on this, that they must collect enough annually to pay for the cost of service for the year, plus a profit that can be collected. With respect to the form of the rate so that a proper distribution of the charges may be made, there has been up to the present no basis whatever.

At present, commissions allow power companies annually the annual cost of service exclusive of interest on invested moneys and a certain return on the invested moneys, usually 8 per cent. Inasmuch as the cost of money is as definite as the cost of copper wire, it would seem to be better to determine the entire cost of service and then allow a certain percentage of profit or a commission for the execution of this service. And this commission should be in proportion to the efficiency of the system, the degree of wisdom and foresight displayed in necessary investments, the ability displayed in the development of business etc.; in other words, the quality, price also considered, of the service. Thus an efficient power company should receive a greater return than an inefficient one.

It is time to develop in these matters along broad and permanent lines, and we trust the above will assist in some degree in so doing. We have had to abbreviate the above greatly, but we hope not so much so, as to sacrifice clearness insofar as we have carried matters in this discussion.

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CLASSIFICATION OF ALTERNATING-CURRENT MOTORS

BY VAL A. FYNN

ABSTRACT OF PAPER

This paper points out that in order to arrive at a rational classification of alternating current motors it is necessary to base all suggestions on one and the same theory. The author thinks that the component field theory is best suited to this purpose, and urges that it be always so applied as to bring out the very great similarity between the alternating and the well understood direct-current machines.

Descriptive names are suggested for some 44 alternating-current motors, including the principal forms of single-phase, polyphase, commutator and commutatorless machines now known. These names are such as to positively identify each of these machines. The rules followed in preparing the diagrams illustrating the various forms of motors and in selecting the proposed names, are given. In order to enable the reader to quickly judge of the aptness of these names, the theory of each of the motors dealt with is briefly outlined. It is thought that the information given will make it easy to correctly represent, describe and classify any motor which may have been omitted.

It is further pointed out that the term "repulsion" as applied to motors, has never been defined, that no practical motors operate on what has been known as the repulsion principle ever since 1820, and that there is no justification whatsoever for the use of this term in connection with alternating-current motors. Such an indefinite term leads merely to endless confusion and should be abandoned. If it is not abandoned, it should be given a rational and definite meaning.

THE OPERATION of dynamo electric machines can always be explained in one of two ways; either by considering the resultant magnetic field, or by dealing with each of the component fields separately throughout the investigation. Both methods lead to correct results provided each is handled with equal skill and accuracy. But it has been my uniform experience that the resultant field theory is much more difficult to apply to alternating-current commutator motors, and although the final result is as correct as that obtained by what may be termed the component field theory, yet the latter gives a very much clearer insight into the intermediate stages, and I believe, approximates much more closely the actual facts. As an illustration, I may state that although I had devoted a number of years to the care-

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ful study of single-phase motors of all types, yet I was unable to make any appreciable progress until, in the 90's, I developed a component field theory of these machines, based on the theory of the ordinary direct-current motor. I firmly believe that students of the present day find themselves in exactly the same position. When the so-called " repulsion motor " is first brought to their attention, they no doubt imagine that they are faced with a machine which stands in a class all by itself and has no relation whatsoever to those with which they are already familiar. The component field theory, based on the theory of the ordinary driect-current motor, immediately dispells this illusion and brings home to the student the fact that the so-called repulsion motor is nothing but an alternating-current form of the well known direct-current series machine. I find that this theory makes it possible to positively and readily identify each of the many single and polyphase motors with and without commutators. An identification based on this theory may, in some cases, require quite a number of words, but there can be nothing astonishing in this fact if it is remembered that a great many of the alternating-current commutator motors only differ from each other in the matter of detail. Knowing of no rational way of more shortly describing such motors except by using coined expressions or by sacrificing accuracy and positiveness, I base the terminology and classification here proposed on the component field theory above referred to.

In the following I will give the rules which I have followed in preparing the appended diagrams and in suggesting names for the various motors which they illustrate. I will also give a short outline of the manner in which each of the motors operates, thus making it easily possible for the reader to judge of the aptness of the suggested designation.

RULES FOLLOWED IN PREPARING DIAGRAMS AND IN SUGGESTING NAMES FOR THE VARIOUS TYPES OF MOTORS

1. *A commuted winding* is represented by a thick circle and is always assumed to be a "left-hand" Gramme ring winding. The brushes are supposed to rest directly on the winding. commutator and commutator connections being dispensed with. The direction of the armature reaction flux is indicated by a straight arrow marked *R*. In the case of a " left-hand " Gramme ring winding the direction of the flow of current from brush to brush corresponds with the direction of the armature reaction flux set up by said current. See Fig. 1.

2. *A distributed stator winding* is indicated by a number of concentric turns with the same axis as that of the resultant magnetization produced by the distributed winding it represents. See winding *F* of Fig. 2.

3. *A unicoil stator winding* is represented by a number of concentric turns and the legend "unicoil." When a winding may be either distributed or unicoil without materially influencing the operation of the machine, the legend " or unicoil " may be added.

4. *A stator winding* adapted to inductively convey working energy to the rotor is marked *W*.

5. *A stator winding* adapted to inductively convey working and exciting energy to the rotor is marked *S*.

6. *A stator winding* adapted to inductively convey exciting energy to the rotor is marked *E*.

7. *A neutralizing winding* is one producing a flux opposed in direction to the armature reaction flux. It is usually disposed on the stator and is marked *N*.

8. *An exciting winding* is one producing or contributing to the production of the motor, or torque producing, field. When located on the stator it is marked *F*.

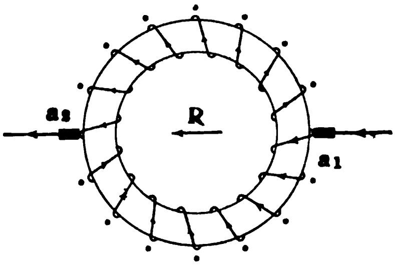

FIG. 1—LEFT HAND GRAMME RING WINDING

9. *A compensating winding* is one producing a flux or generating an e.m.f. used for adjusting the power factor of the machine. When located on the stator it is marked *C*.

10. *Working or armature brushes* are shown black, designated by the letters a_1 a_2 .... a_n and so located with respect to the (rotor) winding with which they cooperate that current directed through said winding by the working brushes. produces nothing but working or armature ampere-turns.

11. *Exciting or field brushes* are shown white, designated by the letters f_1 f_2 .... f_n and so located with respect to the (rotor) winding with which they cooperate that current directed through said winding by the exciting brushes produces nothing but exciting ampere-turns.

12. *Brushes* so located with respect to the (rotor) winding with which they cooperate that current directed by them produces armature or working as well as exciting ampere-turns in said winding, are shown sectioned and designated by the letters b_1 b_2 .... b_n.

13. *A shunt transformer* is designated by the letter *T*.

14. *A series transformer* is designated by the letters *ST*.

15. *Current directed up* through the paper is shown by a circle with a dot in its center.

16. *Current directed down* through the paper is shown by a totally lled in circle.

17. *The direction of rotation* of the motor is shown by a curved arrow.

18. *The direction of the working or exciting current through a stator winding* is indicated by a straight arrow placed alongside said winding. In the case of polyphase motors arrows alongside windings belonging to different phases, show the direction of the current in said windings at a time interval of 180/*n* degrees, where *n* is the number of phases.

19. *The direction of the motor field produced by a rotor winding* is indicated by a straight arrow marked *Fr.*

20. *The armature or working axis* is always placed vertically, *the exciting axis horizontally,* in single-phase motors.

21. The word *commutator* may be omitted in describing a motor having a commutator, provided no equivalent commutatorless machine is known.

22. *A conduction motor* is one in which the energy required by its armature. generally the rotor, is conveyed to it by conduction. When nothing to the contrary is stated, it will be assumed that the machine spoken of *is* of the conduction type.

23. *An induction motor* is one in which the energy required by its armature, generally the rotor, is conveyed to it by induction.

24. *A series motor* is one in which the field excitation varies in some proportion with the armature current, and the speed of which, therefore, varies with varying load.

25. *A shunt motor* is one in which the working and exciting e.m.f.'s remain practically constant independently of the load. The speed of such motors will generally be constant for all loads, but will not necessarily be a nearly synchronous one.

26. *A compensated motor* is one in which means, other than a neutralizing winding, are provided for adjusting (improving) the power factor of the machine.

27. *A motor with stator excitation* is one in which the motor, or torque-producing, field is due to a winding disposed on the stator. When nothing to the contrary is stated, it will be assumed that the motor in question *has* stator excitation.

28. *A motor with rotor excitation* is one in which the motor or torque-producing, field is due to a winding located on the rotor.

29. *A separately-excited motor* is one in which the field excitation is derived from the mains, either directly or through the agency of apparatus which is independent of the motor itself, and whether the exciting current is taken to a winding on the rotor or on the stator. When nothing to the contrary is said, it will be assumed that the motor *is* separately-excited.

30. *A self-excited motor* is one in which the exciting current is due to an e.m.f. generated in the motor itself by induction. Such an e.m.f. may be generated in the rotor by rotation in a flux, or by static induction from the stator, or it may be generated in the stator by static induction from the rotor, or from the stator.

31. *A motor with mixed excitation* is one which is separately as well as self-excited.

32. *A conductively-neutralized motor* is one in which the armature re-

action flux is neutralized by means of a winding (generally located on the stator) connected in series relation with the armature brushes. In speaking of such a machine it will be sufficient to refer to it as a *neutralized motor.*

33. *An inductively neutralized motor* is one in which the circuit of the neutralizing winding is closed independently of the armature brushes and is placed in inductive relation to the armature reaction flux. Note that an induction motor is *ipso facto* an inductively neutralized motor.

34. *A motor with independent brushes* is one in which brushes which are not interconnected and not connected to the supply so cooperate with the commutator as to each short circuit a number of the coils of the commuted winding.

35. *A single-phase motor* is one which receives the whole of the working energy it requires from only one phase of an alternating-current supply. It may receive its exciting energy from the same or from another phase.

36. *A polyphase motor* is one which receives working energy from a plurality of phases of an alternating-current supply.

37. When diagrams represent machines with more than two poles, a legend to that effect should appear.

PROPOSED NAMES AND THEORY OF OPERATION

MOTORS WITH SERIES CHARACTERISTIC

Single-Phase Series (Conduction)* *Motor.* Fig. 2.

Two co-phasal fluxes, *R* and *F*, are set up in this machine. The flux *R* is due to the rotor ampere-turns. The flux *F* is located at 90 electrical degrees to *R*, and is due to the stator ampere-turns *F*. *R* performs no useful work. *F* cooperates with all the rotor ampere-turns to produce the motor torque and is therefore the motor flux or field. Energy is conveyed to armature and field windings conductively. The back e.m.f. is generated in the armature conductors by rotation in the motor field and appears at the brushes a_1 a_2. The machine has a series characteristic, because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns, and the torque per ampere is independent of the power factor. The machine does not possess any inherent power-factor-improving qualities; in other words, it is not self-compensating. Its power factor

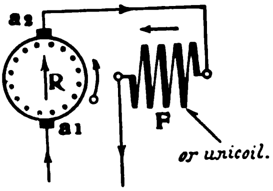

FIG. 2 — SINGLE - PHASE SERIES (CONDUCTION) MOTOR

is low at all speeds, principally because of the high armature inductance, but rises with increasing speed. The machine may be reversed by changing the direction of the current through the armature or through F. The stator may or may not have defined polar projections. The field winding may be of the distributed or of the unicoil type.

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*Terms included in brackets are not supposed to form part of the proposed name and are added merely for the sake of explanation.

Neutralized Single-Phase Series (Conduction) *Motor.* Fig. 3.

This differs from the motor shown in Fig. 2, only in that the armature reaction flux R, which performs no useful work, is neutralized by means of the stator winding N located and dimensioned to produce a flux equal and opposite to R. The neutralizing winding N is in conductive relation to the armature circuit and should be of the distributed type in order to secure the best results. The power factor of this machine is higher than that of the one shown in Fig. 2, because of the lower self-induction of the rotor, but the machine is not self-compensating, although very high power factors can be reached at speeds above the synchronous.

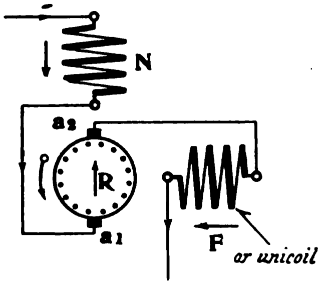

FIG. 3—NEUTRALIZED SINGLE-PHASE SERIES (CONDUCTION) MOTOR

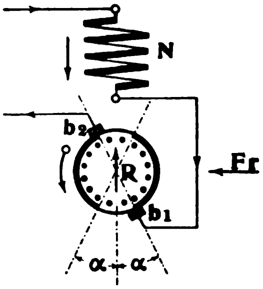

FIG. 4—NEUTRALIZED SINGLE-PHASE SERIES (CONDUCTION) MOTOR WITH ROTOR-EXCITATION

Neutralized Single-Phase Series (Conduction) *Motor with Rotor-Excitation.* Fig. 4.

There are three-cophasal fluxes, N, R and Fr, in this machine. The flux N is due to the stator ampere-turns N, each of the others is due to part of the rotor ampere-turns. The total rotor ampere-turns exceed the stator ampere-turns, and the brushes b_1 b_2 are so displaced with respect to the axis of N that the flux R due to the rotor ampere-turns comprised within the angle $360 - 4\alpha$ degrees equals and opposes N. The remaining rotor ampere-turns comprised within the angle 4α produce the flux *Fr* at 90 electrical degrees to the two others. The rotor ampere-turns distributed along those parts of the rotor circumference which are distinguished by heavier lines $(360 - 4\alpha)$ do duty as armature ampere-turns. The remaining rotor ampere-turns $(4\ \alpha)$ do duty as field ampere-turns, producing the only really existing field *Fr* of the machine. *Fr* is the motor field, it co-operates with the armature ampere-turns on the rotor to produce the motor torque. Energy is conveyed to armature and field windings conductively. The back e.m.f. is generated in the armature conductors of the rotor $(360 - 4\alpha)$ by rotation in the motor field *Fr*. The machine has a series characteristic because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns, and the torque per ampere is independent of the power-factor. The machine is not self-compensating, but its power factor rises with increasing speed. It may be reversed by moving the brushes through $2\ \alpha$ degrees against the direction of the initial rotation; this reverses the direction of the motor field but not that of the armature ampere-turns on the rotor. The stator may or may not have defined polar projections. The neutralizing winding should preferably be of the distributed type.

Because of the *conductive relation* between stator and rotor windings in Fig. 4, there is no fixed relation between the ampere-turns in *N* and the coaxial rotor ampere-turns. Provided there are more turns on the rotor than on the stator, it is always possible to so locate the brushes b_1 b_2 as to make the vertical rotor ampere-turns equal and opposite to the *N* ampere-turns. It follows that it must also be possible to so locate said brushes as to make the vertical rotor ampere-turns either larger or smaller than those of *N*. It should be noted that no such condition can be secured in case the relation between stator and rotor windings is inductive instead of conductive.

When the rotor turns exceed those of *N*, a value of α differing from zero can be found for which the vertical rotor ampere-turns are greater than the *N* ampere-turns. In such a case a flux *R N* will be present along the axis of *N*, in addition to the motor field *Fr* along the horizontal axis. This additional flux *R N* cooperating with the rotor ampere-turns responsible for *Fr* and located within 4α degrees, will develop a *negative* torque, *i.e.*, one opposed in direction to that due to the interaction of

Fr and of the armature ampere-turns $(360 - 4\alpha)$ on the rotor. Otherwise the machine will behave as before.

If α is so chosen as to make the vertical rotor ampere-turns smaller than those of *N*, then a flux *N R* will be present along the axis of *N* in addition to *Fr* in the horizontal axis, and the flux *N R* cooperating with the rotor ampere-turns responsible for *Fr*, will develop a ***positive*** torque. Otherwise the machine will behave as before.

Inductively-Neutralized Single-Phase Series (Conduction) *Motor.* Fig. 5.

This machine differs from that shown in Fig. 3 only in that the neutralizing winding *N* is in inductive instead of conductive relation to the armature ampere-turns. A motor of this kind must always be under neutralized, since no current can be induced in *N* unless a flux of mutual induction is present, which flux must be supplied by armature ampere-turns. A conductively neutralized motor (Fig. 3) can, on the other hand, be neutralized or over neutralized to any desired degree. The lower the ohmic resistance of *N* in Fig. 5, and the better its inductive relation to the armature ampere-turns, the more complete the neutralization of the armature self-induction. The flux of mutual induction along the brush axis only affects the commutation. The machine shown in Fig. 5 otherwise operates just the same as that illustrated in Fig. 3.

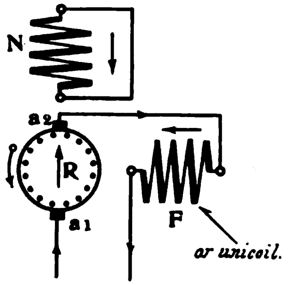

Fig. 5—Inductively-Neutralized Single-phase Series (Conduction) Motor

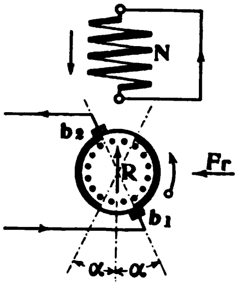

Fig. 6—Inductively Neutralized Single-phase Series (Conduction) Motor with Rotor-Excitation

Inductively-Neutralized Single-Phase Series (Conduction) *Motor with Rotor-Excitation.* Fig. 6.

There are four fluxes to be considered in this machine: A vertical flux of mutual induction due to a magnetizing current circulating in the rotor; a vertical armature reaction flux *R* due to the true rotor working current; an equal and opposite flux due to the current induced in *N*; and a horizontal flux *Fr* due to the total rotor current, *i.e.*, to the vectorial sum of rotor magnetizing and working currents. *R* and *N* perform no useful work and cancel each other. *Fr* cooperates with the total rotor ampere-turns comprised within $360 - 4\,\alpha$ degrees, to produce the main motor torque. The vertical flux of mutual induction is usually very small because of the low impedance of *N*. This flux affects commutation and produces a subsidiary torque with the total rotor ampere-turns responsible for *Fr* and located within $4\,\alpha$ degrees. This subsidiary torque is negative and dminishes rapidly with increasing speed, reaches zero, and may become positive. It is small at any time because of the smallness of the vertical flux of mutual induction. By rotation of the motor field producing turns ($4\,\alpha$) in said flux, an e.m.f. is generated in the rotor which increases its impedance, thereby lowering the power factor of this machine. This effect is, however, small because the vertical flux of mutual induction is small at all speeds and decreases with increasing speed.

Energy is conveyed to armature and field windings conductively. The back e.m.f. is generated in the armature conductors comprised within $360 - 4\,\alpha$ degrees by rotation in the motor field produced by the rotor conductors comprised within $4\,\alpha$ degrees. The machine has a series characteristic, because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns and the torque per ampere is independent of the power factor. The power factor is slightly worse than that of Fig. 5. The machine may be reversed by moving the brushes past the axis of *N* and against the initial direction of rotation. It should be noted that because of the inductive relation between rotor and stator the total rotor ampere-turns, as well as those in the axis of *N*, must always exceed the ampere-turns in *N*, regardless of the magnitude of α. The stator may or may not have defined polar projections. The neutralizing winding should be distributed.

Inductively-Neutralized Single-Phase Series (Conduction). *Motor with two Conductively Related Rotor Circuits.* Fig. 7

The mode of operation and characteristics of this machine are identical with those of the previous one, with this difference, that the armature and the field ampere-turns on the rotor are produced in independent but conductively linked rotor windings. One of these does exclusive duty as armature and the other exclusive duty as field winding. This machine may be reversed by reversing the current through the rotor armature winding cooperating with the brushes a_1 a_2, or through the rotor field winding cooperating with the brushes f_1 f_2.

Neutralized Series (Conduction) *Motor with two Inductively Related Rotor Circuits.* Fig. 8.

The mode of operation and characteristics of this machine are identical with those of the one shown in Fig. 4, with this difference, that the whole of the rotor winding is made use of as armature winding along one axis and as field winding along an axis at right angles to the first. To this end, independent armature or working brushes a_1 a_2 and field or exciting brushes f_1 f_2 are used, the two rotor circuits being inductively linked by means of a series transformer S T. Whether an additional torque is produced between the field armpere-turns and the flux R N or N R depends on the number of turns in N. The direction of rotation may be reversed by reversing the current through the working circuit N, a_1 a_2, S T, or the exciting circuit f_1 f_2, ST.

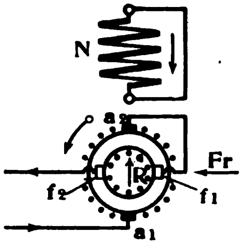

FIG. 7—INDUCTIVELY-NEUTRALIZED SINGLE-PHASE SERIES (CONDUCTION) MOTOR WITH TWO CONDUCTIVELY RELATED ROTOR CIRCUITS

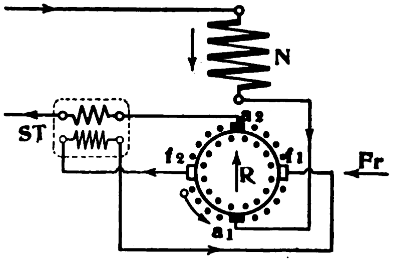

FIG. 8—NEUTRALIZED SERIES (CONDUCTION) MOTOR WITH TWO INDUCTIVELY RELATED ROTOR CIRCUITS

Neutralized and Compensated Series (Conduction) *Motor with two Inductively Related Rotor Circuits.* Fig. 9.

This motor differs from the previous one only in that the compensating winding C has been added. The flux produced by C lags about 90 electrical degrees behind the terminal e.m.f.; it affects the commutation under the brushes a_1 a_2, cooperates with the exciting ampere-turns on the rotor to produce an auxiliary torque, and is responsible for a compensating speed e.m.f. appearing at the brushes $f_1 f_2$ and of course due to the rotation of the rotor conductors in the flux C. At starting, the effect of C on commutation is negligible, and it has no phase-compensating influence, but contributes an appreciable and positive auxiliary torque. As the speed increases the auxiliary torque diminishes, and may reverse, but the compensating effect and the influence of C on the commutation increase.

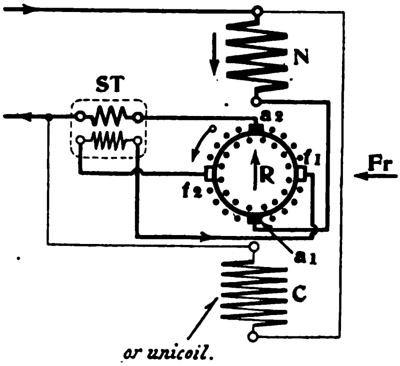

FIG. 9—NEUTRALIZED AND COMPENSATED SERIES (CONDUCTION) MOTOR WITH TWO INDUCTIVELY RELATED ROTOR CIRCUITS

Single-Phase Series (Conduction) *Motor with Mixed* (Stator) *Excitation.* Figs. 10 and 11.

This machine, devised in 1888,* is one of the earliest single-phase commutator motors, but is somewhat difficult to represent diagrammatically along the lines adopted in all other cases; one attempt in this direction is illustrated in Fig. 11.

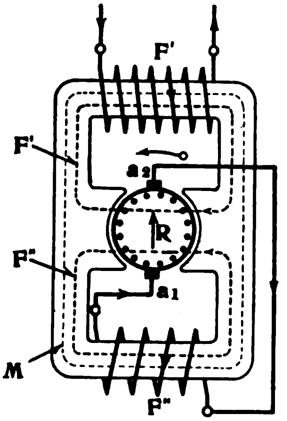

FIG. 10—SINGLE PHASE SERIES (CONDUCTION) MOTOR WITH MIXED (STATOR) EXCITATION

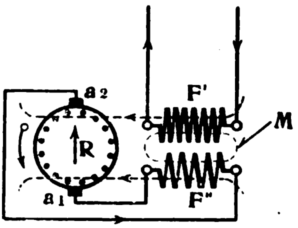

FIG. 11—SINGLE-PHASE SERIES (CONDUCTION) MOTOR WITH MIXED (STATOR) EXCITATION

Referring more particularly to Fig. 10, there are four fluxes to consider: A flux of mutual induction M linking the primary stator winding F' connected to the mains with the secondary stator winding F'' connected to the rotor winding. This flux closes without passing through the rotor. A flux R due to the rotor ampere-turns and threading the rotor in a vertical direction. A flux F'' threading the rotor in a horizontal direction and due to the ampere-turns in the secondary stator winding F''. A flux F' also threading the rotor in a horizontal direction but due to ampere-turns in the primary stator winding F', which are equal to those in F'' but oppose the latter along the path of the flux of mutual induction M. The primary of the transformer F' F'' carries magnetizing current and load current as is usual; the secondary carries load current only. The flux M is practically in phase with the primary magnetizing current; the fluxes F' and F'' are practically in phase with and proportional to the load currents in primary and secondary respectively, and are therefore in phase with each other. The flux R is in phase with and proportional to the rotor ampere-turns. The fluxes F' and F'' cooperate with all the rotor ampere-turns and produce the motor torque, and are therefore the motor fields. The field excitation is derived in part directly from the mains through the primary F', and is in part generated in the rotor itself by static induction from F' to F'', M conveys energy from F' to F'', from which winding it is conductively transferred to the rotor by way of the brushes a_1 a_2. The whole rotor does duty as armature, and R is therefore the armature reaction flux; it does no useful work and can be neutralized with advantage. The back e.m.f. is generated in the armature conductors by rotation in the motor field $F' + F''$. The machine has a series characteristic, because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns, and the torque per ampere is independent of the power factor. The machine is not self-compensating. Other things being equal, its power factor is somewhat lower than that of Fig. 2, for instance, because of the flux M. If a neutralizing winding is added, the power factor will be comparable with that of the motors shown in Fig. 3 or 5. The machine may be reversed by changing the direction of the current through the armature. The stator should have defined polar projections. The field windings should be of the unicoil type. This machine is really a combination of a reducing transformer with a motor. The primary and secondary windings of the transformer also do duty as field exciting windings for the motor, the rotor of which receives its energy from the secondary of said transformer by conduction.

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*See U. S. P. 591,301.

Inductively-Neutralized and Self-Excited Single-Phase Series (Conduction) *Motor with Rotor-Excitation.* Fig. 12.

Four fluxes are to be considered: A vertical flux of mutual induction linking rotor and stator windings and due to a magnetizing current circulating through the rotor; a vertical armature reaction flux *R* due to what may be referred to as the true rotor working current; an equal and opposite flux due to the current induced in *N*; and a horizontal flux *Fr* due to the current induced in *N* but circulating through the rotor along the axis $f_1\,f_2$. *R* and *N* perform no useful work and cancel each other. *Fr* cooperates with the total vertical rotor ampere-turns, *i.e.*, those due to the rotor magnetizing as well as to the true rotor working current, to produce the main motor torque. The vertical flux of mutual induction is large, because of the high impedance of the exciting circuit $f_1\,f_2$, fed by the neutralizing winding *N*. Said flux affects the commutation under the working brushes $a_1\,a_2$, produces an auxiliary, appreciable and negative torque with the rotor exciting ampere-turns, and is responsible for the appearance, at the exciting brushes, of a speed e.m.f. of such phase as to increase the impedance of the exciting circuit and therefore to lower the power factor of the machine.

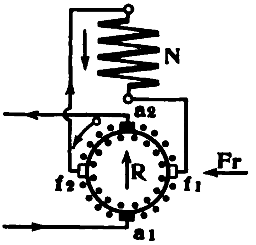

Fig. 12—Inductively-Neutralized and Self-Excited Single-Phase Series (Conduction) Motor with Rotor-Excitation

Energy is conveyed to the armature by conduction. The exciting e.m.f. is generated in the neutralizing winding *N* by induction from the rotor. The back e.m.f. is generated in the vertical rotor axis by rotation of the rotor conductors in *Fr*. The machine does not possess a true series characteristic because of the strong negative and irregularly varying torque due to the vertical flux of mutual induction, and because the phase relation between *Fr* and the vertical rotor ampere-turns is a variable one. The power factor is low at all speeds. The machine may be reversed by reversing the connections between *N* and the horizontal rotor axis. The general performance is very poor.

Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation. Fig. 13.

The theory of this machine becomes self-evident the moment one realizes that the only difference between it and the motor shown in Fig. 4, is that, in the latter, energy is conveyed to the rotor by conduction whereas in this case it is conveyed to the rotor by induction.. In order to convert Fig. 4 into Fig. 13, it is, indeed, only necessary to short circuit the brushes b_1 b_2.

There are four fluxes to consider. A vertical flux of mutual induction (transformer flux) due to a magnetizing current circulating in the primary or stator winding S; a vertical rotor flux R due to the current induced by the transformer flux in the short circuited secondary or rotor and circulating in the rotor conductors located within $360-4\alpha$ degrees; an equal and opposite, *i.e.* neutralizing, flux, due to the corresponding current in S; and a horizontal flux Fr due to the current induced in the rotor and circulating in the conductors located within 4α degrees and therefore out of inductive relation with the stator winding S. The flux R and the opposing stator flux are co-phasal with the flux Fr; they cancel each other and therefore perform no useful work. Fr cooperates with the rotor conductors responsible for R $(360-4\alpha)$ in producing the main motor torque. The vertical flux of mutual induction cooperates with the rotor conductors (4α) responsible for Fr to produce an auxiliary and positive torque, which diminishes as the power factor of the motor improves. This flux is also responsible for a speed e.m.f., generated by rotation in said flux of the rotor conductors located within 4α degrees. This e.m.f. is of a phase adapted to decrease the rotor impedance, thus improving the power factor of the motor. This inherent quality cannot raise the power factor to unity, but it improves it materially, thus rendering the machine *self-compensating*. This self-compensation increases with increasing transformer flux and speed.

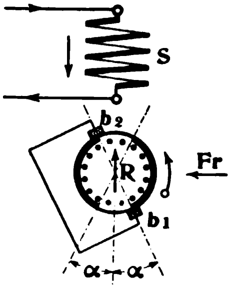

FIG. 13—SELF-EXCITED SINGLE-PHASE SERIES INDUCTION MOTOR WITH ROTOR-EXCITATION

Energy is conveyed to the rotor conductors doing duty as armature $(360-4\alpha)$ and to those doing duty as field windings (4α), inductively. The back e.m.f. is generated in the armature conductors by rotation in Fr; it reduces the current in the secondary (rotor) and increases the flux of mutual induction, linking the rotor with the primary *S*. The machine has a series characteristic because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns, and the main torque is independent of the power factor. The auxiliary torque is too small to materially affect the torque characteristic within the normal speed range. The power factor rises to near unity about synchronism. The machine may be reversed by moving the brushes though α degrees against the direction of the initial rotation, whereby the direction of *Fr* only is reversed. The stator should have no defined polar projections, and the stator winding should be distributed.

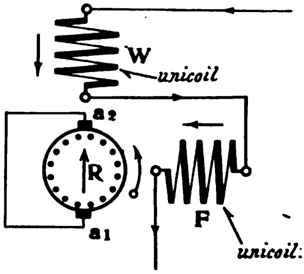

FIG- 14—SINGLE-PHASESERIES INDUCTION MOTOR (WITH STATOR-EXCITATION)

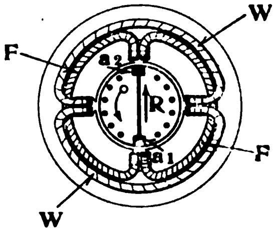

FIG. 15—SINGLE-PHASE SERIES INDUCTION MOTOR (WITH STATOR-EXCITATION)

Single-Phase Series Induction Motor (with Stator-excitation) Figs. 14 and 15.

The actual distribution of the stator windings diagrammatically indicated in Fig. 14, is shown in Fig. 15. It is clear that *F* can have no statically inductive effect on the rotor winding which can make itself felt within the brush circuit, but the rotor will be fully responsive to the inductive effect of *W*. There are four fluxes to consider: A transformer flux due to a magnetizing current in *W*; an armature reaction flux *R* due to the ampere-turns induced by *W* in the rotor; an equal and opposite flux due to the corresponding neutralizing ampere-turns in *W*; and an exciting flux *F* due to the stator magnetizing and neutralizing currents flowing through *F*. The flux *R* is neutralized by the opposing flux due to *W* and does no useful work. The flux of mutual induction affects the commutation only. *F* produces the motor torque in cooperation with all of the rotor ampere-turns.

Energy is conveyed to the armature inductively and to the field winding conductively and directly from the mains. The back e.m.f. is generated in the armature conductors by rotation in the motor field and appears at the brushes a_1 a_2; it decreases the rotor current and increases the transformer field. The machine has a series characteristic because the motor field varies practically in proportion with the armature current at all but very light loads. The motor field is always a little out of phase with the armature current, and the torque per ampere is almost independent of the power factor, which is low at all speeds. The machine may be reversed by changing the direction of the current through F or through W.

Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and Independent Brushes. Fig. 16.

This is the modern form of the motor invented by Elihu Thomson, in 1887,* and referred to by him as a "repulsion motor." Only one brush may be used, and the width of each brush may vary within wide limits.

There are four fluxes to consider: A vertical flux of mutual induction (transformer flux) due to a magnetizing current circulating in the primary or stator winding S; a vertical rotor flux R due to the vertical component of the current induced by the transformer flux in the coils short circuited by the brushes b; an equal and opposite, *i.e.*, neutralizing, flux due to the corresponding current in S; and a horizontal flux Fr due to the horizontal component of the current induced in the short circuited rotor coils. The flux R, the opposing stator flux, and Fr are co-phasal; the first two cancel each other and therefore perform no useful work. Fr cooperates with the rotor ampere-turns responsible for R to produce the main motor torque. The vertical flux of mutual induction cooperates with the rotor ampere-turns responsible for Fr, to produce a positive auxiliary torque which diminishes as the power factor improves. By revolution of the rotor conductors in this transformer flux, a compensating e.m.f. is generated within the rotor short circuits, tending to raise the power factor of the machine.

Working and exciting energy is conveyed to the rotor by induction. The back e.m.f. is generated in the rotor short circuits by rotation in Fr, and tends to decrease the rotor current and increase the flux of mutual induction. The machine has a series characteristic, because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns, and the torque per ampere is independent of the power factor. The power factor is good at speeds near the synchronous. The machine may be reversed by shifting the brushes into the other quadrants. This machine is not now used; it is much inferior to that shown in Fig. 13, although it has the same general characteristics as the latter.

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*See U. S. P. 363, 185.

Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and two Independent Rotor Circuits. Fig. 17.

This machine operates exactly like that shown in Fig. 16, but utilizes the rotor copper much more efficiently and with much smaller friction losses. Electrically, the result is the same whether one short circuits the brushes b_1 b_2 by means of a conductor or replaces them by a single brush covering the arc previously short circuited by the two interconnected brushes. The arrangement shown in Fig. 17 is practical and allows of a wide regulation of the motor, for instance by moving the brushes b_2 and b_3.

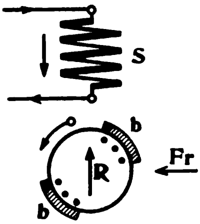

FIG. 16—SELF-EXCITED SINGLE-PHASE SERIES INDUCTION MOTOR WITH ROTOR-EXCITATION AND INDEPENDENT BRUSHES

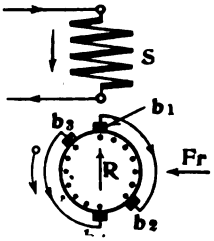

FIG. 17—SELF-EXCITED SINGLE-PHASE SERIES INDUCTION MOTOR WITH ROTOR-EXCITATION AND TWO INDEPENDENT ROTOR CIRCUITS

Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and two Inductively Related Rotor Circuits. Fig. 18.

The mode of operation and characteristics of this machine are identical with those of the one shown in Fig. 13, with this difference, that the whole of the rotor winding is made use of as armature winding along one axis and the whole of it is made use of as field winding along an axis at right angles to the first. To this end, independent brushes f_1 f_2 are used, the two rotor circuits being inductively linked by means of the series transformer *ST*. The direction of rotation may be reversed by reversing the direction of the exciting current, which is done by changing the connections between *ST* and the brushes $f_1 f_2$.

Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and two Conductively Related Rotor Circuits. Fig. 19.

The mode of operation and characteristics of this machine are identical with those of the previous one, with this difference that the armature and the field ampere-turns on the rotor are produced in independent but conductively-linked rotor windings. One of these does exclusive duty as armature and the other exclusive duty as field winding. This machine may be reversed by reversing the current through the rotor winding doing duty as field winding. The machine is less flexible than that shown in Fig. 18, because of the absence of the transformer, which can of course be of the adjustable ratio type.

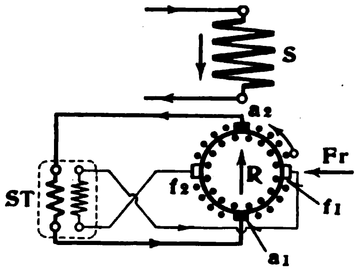

Fig. 18—Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and Two Inductively Related Rotor Circuits

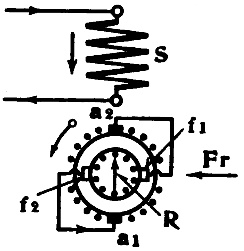

Fig. 19—Self-Excited Single-Phase Series Induction Motor with Rotor-Excitation and Two Conductively Related Rotor Circuits

Self-Excited Single-Phase Series Induction Motor (with Stator-Excitation). Fig. 20.

Four fluxes must be taken into account: A vertical flux of mutual induction due to a magnetizing current in *S*; a vertical armature reaction flux *R* due to the ampere-turns induced in the rotor by *S*; an equal and opposite flux due to corresponding ampere turns in *S*; and a horizontal flux due to the stator winding *F* through which is sent the current induced in the rotor by *S*. The flux *R* and the corresponding stator flux cancel each other. *F* cooperates with all the rotor ampere-turns to produce the motor torque. The flux of mutual induction affects only the commutation.

Working and exciting energy is conveyed to the rotor from S by induction. The back e.m.f. is generated in the rotor, *i.e.*, armature conductors, by rotation in the motor flux F. The machine has a series characteristic, because the motor field varies in proportion with the armature current. The motor field is always practically in phase with the armature ampere-turns and the torque per ampere is independent of the power factor. The machine is not self-compensating; its power factor is lower than that of Fig. 13, for instance, but increases with rising speed. The machine may be reversed by reversing the direction of the current through the stator field winding.

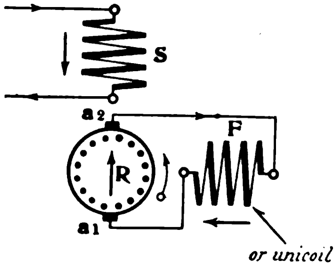

FIG. 20—SELF-EXCITED SINGLE-PHASE SERIES INDUCTION MOTOR (WITH STATOR-EXCITATION)

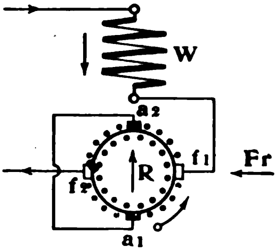

FIG. 21—(SEPARATELY-EXCITED) SINGLE-PHASE SERIES INDUCTION MOTOR WITH ROTOR-EXCITATION

(Separately-Excited) *Single-Phase Series Induction Motor with Rotor Excitation.* Fig. 21.

The mode of operation and characteristics of this machine are readily recognized when it is realized that the only difference between it and the motor shown in Fig. 18, is that the motor flux Fr in that figure is produced by the secondary current of the static transformer $S - a_1 a_2$, whereas in Fig. 21, this flux is produced by the primary current of the transformer $W - a_1 a_2$. While the motor field exciting current in Fig. 18 is strictly in phase with the working current threading the rotor along the vertical axis, and the phase difference between the motor flux Fr and the rotor working ampere-turns amounts merely to the small iron lag of Fr behind the current producing it, in the machine under discussion the phase difference between Fr and the rotor working ampere-turns is increased by the phase difference between the secondary and primary currents of the transformer $W - a_1 a_2$. This phase difference is, of course, due to the magnetizing current in the primary *W*, which is responsible for the flux of mutual induction in the vertical axis, and which conveys the working energy to the rotor. This motor is said to be separately excited, because the exciting energy is taken directly from the mains. The vertical flux of mutual induction is responsible for an auxiliary and positive torque, as in all similar machines, and also for a phase compensating speed e.m.f. which appears at the exciting brushes $f_1 f_2$ and is thus introduced directly into the primary or stator circuit, instead of being first generated in the secondary or rotor circuit, as in Figs. 13 and 16 to 19 inclusive. This speed e.m.f. reduces the impedance of the primary or stator circuit and thus raises the power factor of the machine. A series transformer may be interposed between *W* and the horizontal rotor axis without affecting the mode of operation or the characteristics of the machine; but the use of such a transformer adds to the flexibility of the motor.

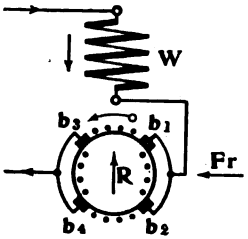

FIG. 22—(SEPARATELY-EXCITED) SINGLE-PHASE SERIES INDUCTION MOTOR WITH ROTOR-EXCITATION

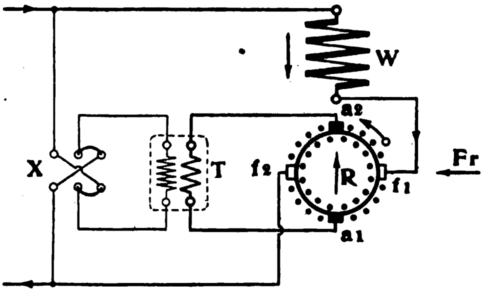

FIG. 23—(SEPARATELY-EXCITED) SINGLE-PHASE SERIES INDUCTION-CONDUCTION MOTOR WITH ROTOR-EXCITATION

(Separately-Excited) *Single-phase Series Induction Motor with Rotor-Excitation.* Fig. 22.

This machine is identical with that shown in Fig. 21, except for the arrangement of the brushes cooperating with the rotor winding. The latter is here short circuited along the lines $b_1 b_2$ and $b_3 b_4$, both of which are parallel to the axis of the stator winding *W*, whereas in Fig. 21, the rotor is short circuited along the very axis of *W*. The current induced in the rotor and producing the armature reaction flux *R*, only circulates in those rotor conductors which are spanned by the two short circuits.

The distribution of this current is shown by dots and circles placed inside the rotor winding. The primary current, producing *Fr*, and conducted through the rotor by way of the short circuited brush groups, only circulates in the remaining rotor conductors, as shown by the dots and circles placed outside the rotor winding. Because the same brushes carry the induced working and the conduced exciting current, they are shown sectioned.

(Separately-Excited) *Single-Phase Series Induction-Conduction Motor with Rotor Excitation.* Fig. 23.

In Fig. 21 the working energy along the working axis is entirely conveyed to the rotor by induction. The entire rotor working e.m.f. in said axis *is induced* in the rotor and depends on and varies with the voltage at the terminals of *W*. This working e.m.f. is always of approximately the same phase as the line e.m.f. These conditions are taken advantage of in Fig. 23 to adjust the magnitude of the rotor working e.m.f. independently of *W*, by *conductively* injecting an additive or subtractive and approximately co-phasal e.m.f. into the working axis of the rotor. This auxiliary e.m.f. is derived from the mains by means of the transformer *T* and the reversing switch *X*. When the auxiliary e.m.f. is of the same direction as the induced working e.m.f., then the vertical axis of the rotor receives energy conductively, as well as inductively. If the direction of the auxiliary e.m.f. is reversed, then part of the energy inductively conveyed to the vertical axis is conductively withdrawn therefrom and conveyed back to the mains. Hence the term " induction-conduction " applied to this machine. Except for the regulation obtained by changing the magnitude or direction of the auxiliary e.m.f. conducted into the vertical rotor axis, the mode of operation and characteristics of the machine are identical with those of the motor shown in Fig. 21.

Neutralized Two-Phase Series (Conduction) *Motor.* Fig. 24.

This is the two-phase equivalent of the single-phase motor shown in Fig. 3. It is obtained by combining two single-phase Fig. 3 motors in one frame and displacing all the elements of one of them by 90 electrical degrees with respect to the corresponding elements of the other. A single rotor winding may be used, as shown in Fig. 24, if interconnection of the phases is permissible. The field winding F_1 of phase 1, does not interfere with the proper working of the armature circuit belonging to phase 2, because any e.m.f. induced by F_1 at the brushes a_3 a_4 is equalled and opposed by an e.m.f. induced by F_1 in N_2. The effect of F_2 on the armature circuit of phase 1, is neutralized in the same manner. The fluxes F_1 and F_2 improve the commutation under speed. The available material is of course far better utilized in Fig. 24 than in Fig. 3.

Neutralized Two-Phase Series (Conduction) *Motor with Rotor-Excitation.* Fig. 25.

This is the two-phase equivalent of the single-phase motor shown in Fig. 4. The brushes b_1 b_2 are displaced by such an angle α from the axis of N_1, that R_1 due to the rotor conductors located within $360 - 4\alpha$ degrees, is neutralized by the flux due to N_1, while the rotor ampere-turns located within $4\,\alpha$ degrees, produce the motor field Fr_1 which co-operates with the rotor ampere-turns responsible for R_1 to produce the motor torque due to phase 1. Similarly, the brushes b_3 b_4 are displaced by such an angle β from the axis of N_2, that R_2 due to the rotor conductors located within $360 - 4\,\beta$ degrees, is neutralized by the flux due to N_2, while the rotor ampere-turns located within $4\,\beta$ degrees produce the motor field Fr_2, which cooperates with the rotor ampere-turns responsible for R_2 to produce the motor torque due to phase 2. The neutralizing windings N_1 and N_2 are displaced by 90 electrical degrees. The two fluxes Fr_1 and Fr_2 improve the commutation under speed.

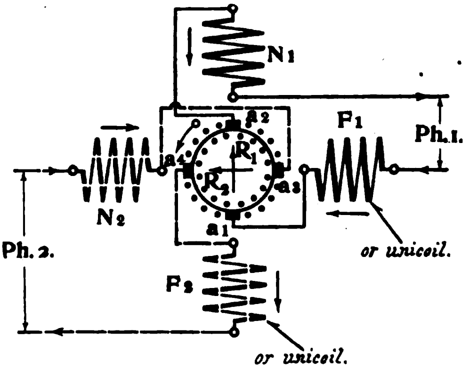

FIG. 24—NEUTRALIZED TWO-PHASE SERIES (CONDUCTION) MOTOR

Motors with Shunt Characteristic

In a series machine no difficulty is experienced in obtaining approximate phase coincidence between motor field and armature current, but the conditions for a shunt machine are very different.

Here the chief problem is to provide an exciting e.m.f. of proper phase.

(Separately-Excited) *Single-Phase Shunt* (Conduction) *Motor* (with Stator-Excitation). Fig. 26.

Two fluxes, *R* and *F*, are set up in this machine. If rotor and stator windings are connected to e.m.fs. of the same phase, then the armature ampere-turns set up by the rotor current and responsible for the useless flux *R*, will, at starting, be about in phase with the useful motor flux *F* set up by the stator field winding *F*, for the impedance of both windings is great. The torque per ampere will be good. Energy is conveyed to armature and field windings conductively. The back e.m.f. is generated in the armature conductors by rotation in the motor field. With increasing speed the lag in the armature circuit quickly diminishes, owing to the effect of the dephased back e.m.f., whereby the power factor is improved, but the torque per ampere is reduced. The machine is said to have a shunt characteristic, because the currents in the armature and in the field circuits are quite independent of each other, but the motor speed under varying load is not as constant as is generally desired. This is due to the phase difference between the working and back e.m.fs., which causes the phase relation between working current and motor flux to vary considerably with the load. When the power factor is low, the torque per ampere is high, and vice versa. The weight efficiency of such a machine is so low as to make it commercially useless except in very small sizes and where no importance is attached to constancy of speed. The stator

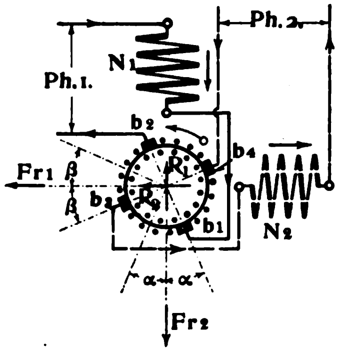

Fig. 25—Neutralized Two-Phase Series (Conduction) Motor with Rotor Excitation

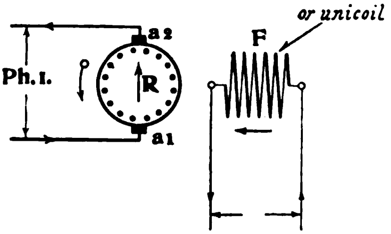

Fig. 26—(Separately-Excited) Single-Phase Shunt (Conduction) Motor (with Stator-Excitation)

may or may not have defined polar projections. The field winding may or may not be of the distributed type.

If rotor and stator windings are connected to e.m.fs. which are in phase quadrature, then the power factor and the torque per ampere are low at starting, and the power factor does not materially change with speed. The speed is more constant, but the weight efficiency is very low.

(Separately-Excited) *Neutralized Single-Phase Shunt* (Conduction) *Motor* (with Stator-Excitation). Fig. 27.

This differs from the foregoing in that the armature reaction flux is neutralized. The armature circuit, comprising the rotor and the stator winding *N* adapted to neutralize the armature reaction flux *R*, is connected to one phase of a two-phase supply, while the stator field winding is connected to the other, and produces the motor field *F*. Because of the leakage fluxes linked with the armature circuit, the armature current lags, at starting, behind the e.m.f. of phase 1, and is therefore not quite in phase with the motor flux due to the e.m.f. of phase 2. The torque per ampere is good, the power factor fair. No phenomena occur under speed to materially change either the torque per ampere or the power factor. The speed of the machine is fairly constant. The weight efficiency is much greater than that of Fig. 26. Much better results can be obtained, particularly under speed, by adjusting the phase of the exciting e.m.f. relatively to that of the working e.m.f. The energy drawn from the phase feeding the armature, varies with the load; that drawn from the other is small and constant.

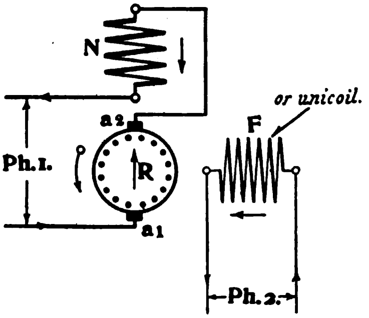

FIG. 27—(SEPARATELY-EXCITED) NEUTRALIZED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR (WITH STATOR-EXCITATION)

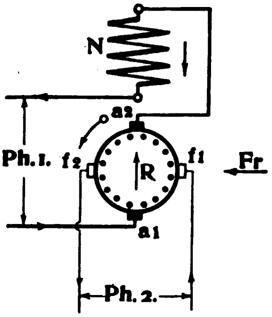

FIG. 28—(SEPARATELY-EXCITED) NEUTRALIZED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR WITH ROTOR-EXCITATION

(Separately-Excited) *Neutralized Single-Phase Shunt* (Conduction) *Motor with Rotor-Excitation.* Fig. 28.

This only differs from the one shown in Fig. 27 in that the stator exciting winding F is dispensed with and the rotor winding along the horizontal axis used in its stead, the exciting e.m.f. being applied to the exciting brushes f_1 f_2. The mode of operation and characteristics of the two machines are identical, except that a speed e.m.f. is generated at the exciting brushes by rotation in the vertical armature leakage flux, which so changes the phase of the resultant e.m.f. in the exciting circuit as to improve the power factor with increasing speed.

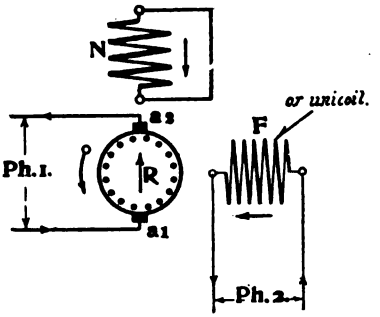

FIG. 29—(SEPARATELY-EXCITED) INDUCTIVELY-NEUTRALIZED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR (WITH STATOR EXCITATION)

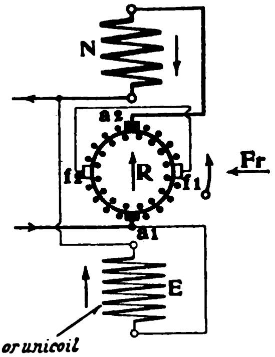

FIG. 30—SELF-EXCITED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR (WITH ROTOR-EXCITATION)

(Separately-Excited) *Inductively-Neutralized Single-Phase Shunt* (Conduction) *Motor* (with Stator-Excitation). Fig. 29.

This differs from the motor shown in Fig. 27 in that the armature reaction flux R is neutralized inductively instead of conductively. The presence, in the vertical rotor axis, of the flux of mutual induction, which conveys the energy from the rotor to N, does not modify the mode of operation or the characteristics of the machine except as to commutation, because the speed e.m.f. generated in the rotor by its rotation in said flux appears along the horizontal rotor axis and is therefore ineffective.

Self-Excited Single-Phase Shunt (Conduction) *Motor* (with Rotor-Excitation). Fig. 30.

The armature circuit comprises the rotor winding along the vertical axis connected in series relation with the neutralizing winding N by way of the working brushes a_1 a_2. The armature reaction flux R is neutralized by N, leaving nothing but leakage fluxes in the vertical axis. The rotor is short circuited along the horizontal axis by means of the field brushes f_1 f_2 to form the exciting or motor field producing circuit. The stator winding E is connected across the mains and produces, in the vertical axis, a flux lagging 90 degrees behind the line or working e.m.f. By rotation of the rotor conductors in the flux E, an e.m.f. in phase with said flux is generated at the brushes f_1 f_2 and produces, along the horizontal rotor axis, a flux Fr lagging 90 degrees behind said e.m.f. and therefore in phase with the line e.m.f. and also with the working current, as long as the same is in phase with the working e.m.f. The flux E does not react on the working circuit because any e.m.f. it induces in the vertical rotor axis is equalled and opposed by the e.m.f. it induces in N. This machine will not start from rest, but is self-compensating, operates well at a constant speed and its speed is readily adjustable.

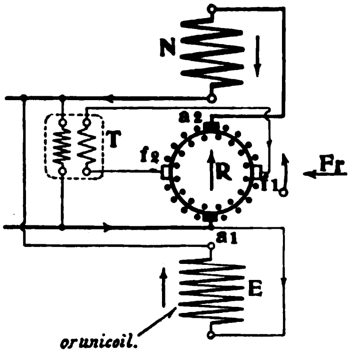

FIG. 31—COMPENSATED SELF-EXCITED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR (WITH ROTOR-EXCITATION)

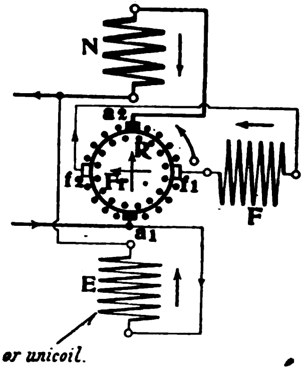

FIG. 32—SELF-EXCITED SINGLE-PHASE SHUNT (CONDUCTION) MOTOR WITH ROTOR AND STATOR-EXCITATION

Compensated Self-Excited Single-Phase Shunt (Conduction) *Motor* (with Rotor-Excitation). Fig. 31.

This differs from the previous motor only in that an e.m.f. differing in phase from the one directly responsible for the motor field and generated in the rotor by rotation, is introduced into the rotor exciting circuits for the purpose of adjusting the power factor of the machine by adjusting the phase of the resultant e.m.f. in the rotor exciting circuit. The compensating e.m.f. is in this case derived from the mains and is therefore in phase quadrature with the rotor exciting e.m.f.

Self-Excited Single-Phase Shunt (Conduction) *Motor with Rotor and Stator-Excitation.* Fig. 32.

This differs from the motor shown in Fig. 30 in that the rotor exciting brushes are not short circuited but closed over a coaxial winding *F* located on the stator. The exciting e.m.f. generated in the rotor by rotation in the auxiliary or teaser flux *E*, sends a magnetizing current through *F*, as well as through the rotor along the horizontal axis, with the result that the motor field is produced in part by rotor, and in part by stator, ampere-turns. Changing the number of active stator exciting turns, or the direction in which they magnetize with respect to the direction of the magnetization produced by the horizontal rotor ampere-turns, changes the magnitude of the motor field independently of the working e.m.f., and therefore influences the speed of the motor. In all other respects the mode of operation and the characteristics are the same as those of Fig. 30.

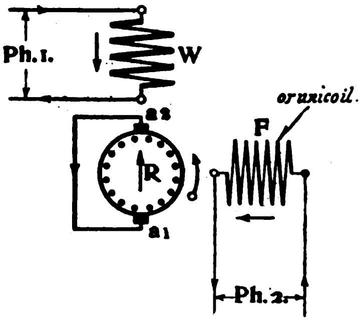

FIG. 33—(SEPARATELY-EXCITED) SINGLE-PHASE SHUNT INDUCTION MOTOR (WITH STATOR-EXCITATION)

(Separately-Excited) *Single-phase Shunt Induction Motor* (with Stator-Excitation). Fig. 33.

Working energy is inductively conveyed to the rotor from phase 1 along the vertical axis by means of a flux of mutual induction (transformer flux) due to a magnetizing current flowing through *W*. The ampere-turns due to the working current thus induced in the short circuited secondary (rotor) are equalled and opposed by corresponding ampere-turns in the primary *W*, set up by a primary working current derived from the mains. The rotor ampere-turns produce the armature reaction flux *R*, which is neutralized by the flux due to the primary working ampere-turns. The leakage flux along the vertical rotor axis is not neutralized, and the armature circuit is therefore not free from impedance. Exciting energy is conductively conveyed to the stator field winding *F* from phase 2, producing a motor field which is nearly in phase with the rotor or armature current and which cooperates therewith to produce the motor torque. In this as in all cases where a motor with one armature and one field axis per pole pair is fed from a two-phase supply, the load on the two phases is quite unequal, the one supplying the excitation being called upon to deliver only a small fraction of the energy required of the other. The machine has no self-compensating properties, and its speed is not constant under varying loads, mainly because of the rotor impedance due to the leakage field in the vertical rotor axis.

The power factor can be improved by suitably adjusting the phase of the motor field, but speed constancy is not secured thereby.

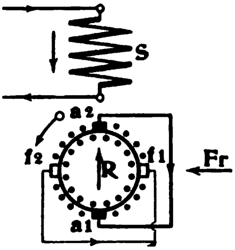

FIG. 34—SELF-EXCITED SINGLE-PHASE SHUNT INDUCTION COMMUTATOR MOTOR (WITH ROTOR EXCITATION)

Self-excited Single-phase Shunt Induction Commutator Motor (with Rotor-Excitation). Fig. 34.

Working energy is conveyed into the rotor along the vertical axis by transformer action from *S*. The induced vertical rotor ampere-turns do duty as armature ampere-turns, and produce the armature reaction flux *R*, which is neutralized by transformer action from *S*. The rotor leakage flux in the vertical axis is not neutralized. The working e.m.f. induced at the working brushes $a_1 a_2$ by the transformer flux, is of about the same phase as the line e.m.f. impressed on the stator winding *S*. The transformer flux lags 90 degrees behind the line e.m.f. The exciting e.m.f. is generated in the rotor by rotation of the rotor conductors in the transformer flux, and appears at the exciting brushes f_1 f_2. This speed e.m.f. is of same phase as the said flux, and therefore in phase quadrature with the line and with the rotor working e.m.fs. The motor flux *Fr* in the horizontal axis, is due to this exciting e.m.f., is in quadrature thereto, and therefore approximately in phase with the rotor ampere-turns in the vertical axis with which it cooperates to produce the motor torque. The back e.m.f. is generated in the vertical rotor axis by rotation in *Fr*. This machine is self-compensating, for another speed e.m.f. is produced at the exciting brushes by rotation of the rotor conductors in the vertical rotor leakage flux. This second speed e.m.f. so alters the phase of the resultant e.m.f. in the horizontal rotor axis, and therefore the phase of the horizontal flux, as to materially improve the power factor of the machine. This self-compensating feature cannot raise the power factor of this motor to anything like unity, but is sufficient to render an otherwise useless machine, operative. The stator should not have any defined polar projections, and the winding *S* should be of the distributed type. This machine will not start from rest, but will run up to speed in any direction in which it is started. Its normal speed is the synchronous.

Compensated Self-Excited Single-Phase Shunt Induction Commutator Motor (with Rotor-Excitation). Fig. 35.

The mode of operation and characteristics of this motor are identical with those of the machine showing in Fig. 34, but auxiliary means are here added whereby the power factor of the machine can be adjusted at will. To this end an adjustable e.m.f., preferably in phase quadrature with the exciting speed e.m.f. generated in the rotor, is conductively introduced into the rotor exciting circuit. In this case this e.m.f. is derived from the mains by way of the transformer *T*. The normal speed of this machine is the synchronous; it is very constant under varying load. The power factor is under perfect control.

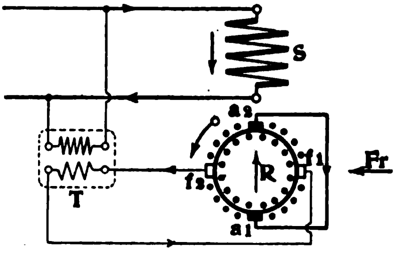

FIG. 35—COMPENSATED SELF-EXCITED SINGLE-PHASE SHUNT INDUCTION COMMUTATOR MOTOR (WITH ROTOR-EXCITATION)

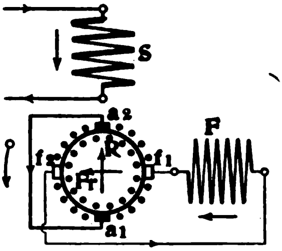

FIG. 36—SELF-EXCITED SINGLE-PHASE SHUNT INDUCTION COMMUTATOR) MOTOR WITH ROTOR AND STATOR-EXCITATION

Self-Excited Single-Phase Shunt Induction (Commutator) *Motor with Rotor and Stator-Excitation.* Fig. 36.

This differs from the motor shown in Fig. 34 in that the exciting brushes are not short circuited but connected through a winding *F* located on the stator and in the horizontal or exciting axis. The exciting e.m.f. generated in the rotor by rotation in the vertical transformer flux sends a magnetizing current through F, as well as through the rotor along its horizontal axis, with the result that the motor field is produced in part by the rotor, and in part by the stator ampere-turns. Changing the number of active stator exciting turns, or the directions in which they magnetize with respect to the direction of the magnetization produced by the horizontal rotor ampere-turns, changes the magnitude of the motor field independently of the working e.m.f., and therefore changes the speed of the motor. This machine can run at speeds other than the synchronous, but in all other respects the mode of operation and the characteristics are the same as those of Fig. 34.

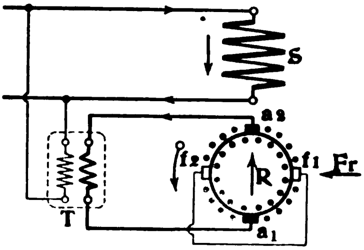

Fig. 37—Self-Excited Single-Phase Shunt Induction-Conduction (Commutator) Motor (with Rotor-Excitation)

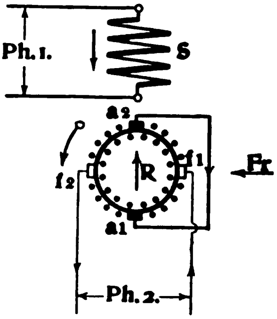

Fig. 38—Single-Phase Shunt Induction (Commutator) Motor with Mixed (Rotor) Excitation

Self-Excited Single-Phase Shunt Induction-Conduction (Commutator) *Motor* (with Rotor-Excitation). Fig. 37.

In Fig. 34, the magnitude of the rotor working e.m.f. in the vertical axis and that of the rotor exciting e.m.f. in the horizontal axis, both depend on the magnitude of the vertical transformer flux. It follows that the magnitude of the working e.m.f. cannot be altered independently of the exciting e.m.f., by changing the magnitude of the transformer flux. In fact, any such change results in a proportional change in both e.m.fs. But an independent regulation of these two e.m.fs. is necessary if the speed of the machine is to be altered; the arrangement shown in Fig. 37 illustrates one way of achieving this result.

An e.m.f. of about the same phase as that of the line e.m.f. is conductively introduced into the working circuit of the rotor by means of the transformer T and the working brushes a_1 a_2.

The working e.m.f. induced in this circuit from S being also of about the same phase as that of the line e.m.f., the two will yield a resultant which will be of about the same phase as the induced working e.m.f., and either greater or smaller than it according to the direction of the conductively introduced component. This resultant will, of course, be the effective rotor working e.m.f. An adjustment of the magnitude of this resultant results in a change of the motor speed. This machine can run at constant speeds differing from the synchronous, but its mode of operation and characteristics are otherwise the same as those of the motor shown in Fig. 34.

Single-Phase Shunt Induction (Commutator) *Motor with Mixed* (Rotor) *Excitation.* Fig. 38.

This differs from the motor shown in Fig. 34 in that an e.m.f. in phase quadrature to that impressed on S is conductively introduced into the rotor exciting circuit. This auxiliary e.m.f. is of about the same phase as that generated in the horizontal rotor axis by rotation in the vertical transformer flux. The resultant of the generated and the auxiliary e.m.f. must be the effective exciting e.m.f., the magnitude of which can therefore be changed independently of the rotor working e.m.f., thus securing speed regulation. This machine will start from rest and can be run at constant speeds differing from the synchronous; in all other respects it is the same as that shown in Fig. 34.

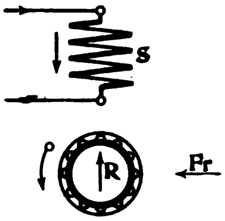

Fig. 39 — Self-Excited Single-Phase Shunt Induction Motor (with Rotor-Excitation)

Self-Excited Single-Phase Shunt Induction Motor (with Rotor-Excitation). Fig. 39.

The mode of operation and characteristics of this machine are identical with those of the motor shown in Fig. 34. The stator winding S produces a vertical transformer flux which conveys the working energy into the rotor and is also responsible for the rotor exciting e.m.f., which is generated in the horizontal axis by rotation of the rotor conductors in this transformer field. The rotor working ampere-turns responsible for the armature reaction flux are neutralized by transformer action from S; their space distribution is shown by the dots and circles located inside the rotor circle in Fig. 34 and remains unaltered independently of the revolution of the rotor. The space distribution of the rotor exciting ampere-turns responsible for the motor torque producing field *Fr*, is as shown by the dots and circles located outside the rotor circle in Fig. 34 and also remains unaltered as long as the rotor revolves. The speed e.m.f. due to rotation of the rotor conductors in the vertical rotor leakage flux, acts to improve the power factor. The squirrel cage construction provides paths over which currents may close through any two rotor conductors, with the result that neither the intensity of the working nor that of the exciting current is the same in all the conductors. The machine will not start from rest, but if given a sufficient impulse in either direction will run up to its normal speed, which is very near the synchronous. Its working speed is practically constant under varying loads.

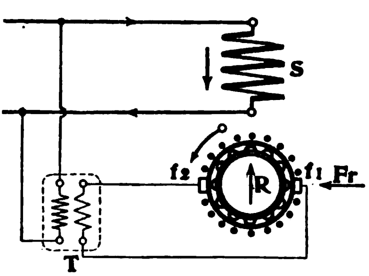

Fig. 40—Compensated Self-Excited Single-Phase Shunt Induction Motor (with Rotor-Excitation)

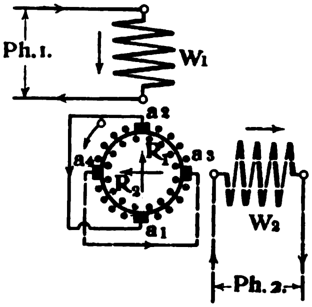

Fig. 41—Two-Phase Shunt-Induction Commutator Motor (with Stator-Excitation)

The stator should not have any defined polar projections, and the stator winding should be distributed.

Compensated Self-Excited Single-Phase Shunt Induction Motor (with Rotor-Excitation). Fig. 40.

This differs from the previous motor in that the rotor carries a squirrel cage, a commuted winding and cooperating brushes located in the horizontal axis. An exciting speed e.m.f. is generated along the horizontal axis of both windings so that both will contribute equally to the production of *Fr* if the brushes f_1 f_2 are short circuited. If the e.m.f. per conductor of one of these windings is artificially raised, this winding will contribute more than one half of the total motor field ampere-turns, and if the increase has been of sufficient magnitude, it may even contribute all of the motor field ampere-turns, in which case there will be no current in the horizontal axis of the other winding.. A further increase will cause a reverse current to flow in the other winding, for the tendency is to keep Fr constant. In Fig. 40 an auxiliary e.m.f. derived from the mains with the help of the transformer T is conductively introduced into the circuit of the commuted winding; its magnitude and phase are such that the burden of the motor field production is shifted to the commuted winding, and the phase of the motor field it produces, is adjusted to improve the power factor of the motor.

Two-Phase Shunt-Induction Commutator Motor (with Stator-*Excitation*). Fig. 41.

This machine really consists of two static transformers with primaries disposed on the stator and displaced by 90 electrical degrees from each other, and a common secondary rendered inductively responsive along the axis of each primary by means of pairs of short-circuited brushes. Each stator winding is connected to one phase of the supply, inductively conveys working energy into the rotor along its own axis by means of a transformer flux, and neutralizes, by transformer action, the armature ampere-turns it induces in its own axis. The transformer flux in one axis cooperates with the rotor ampere-turns in the other axis to produce one half of the motor torque; the other half being due to the interaction of the transformer flux in the second axis with the rotor ampere-turns in the first. Each transformer flux therefore also does duty as a motor field. Under speed, a back e.m.f. is generated in each rotor axis by rotation in the transformer flux at right angles to it. While the armature reaction fluxes R_1 R_2 are neutralized, yet the coaxial rotor leakage fluxes are not. By rotation of the rotor conductors in the vertical rotor leakage flux, a compensating e.m.f. is generated in the horizontal rotor axis, appears at the brushes a_3 a_4, and is of such a phase as to reduce the impedance of the horizontal axis. The impedance of the vertical rotor axis is similarly reduced by an e.m.f. appearing at the brushes a_1 a_2 and generated by rotation of the rotor conductors in the horizontal rotor leakage flux. The machine clearly has self-compensating properties, but the e.m.fs. in question cannot reach a value sufficient to raise the power factor to unity. The normal speed of the machine is very near the synchronous.

Compensated Two-Phase Shunt Induction Commutator Motor (with Stator-Excitation). Fig. 42.

This motor differs from the foregoing in that an auxiliary e.m.f. in quadrature with the induced working e.m.f. is conductively introduced into each of the rotor working or armature circuits by means of the transformers T_1 and T_2. The direction of each auxiliary e.m.f. is chosen to reduce the impedance of the rotor axis to which it is applied. The power factor of the machine can be adjusted by adjusting these *compensating* e.m.fs.

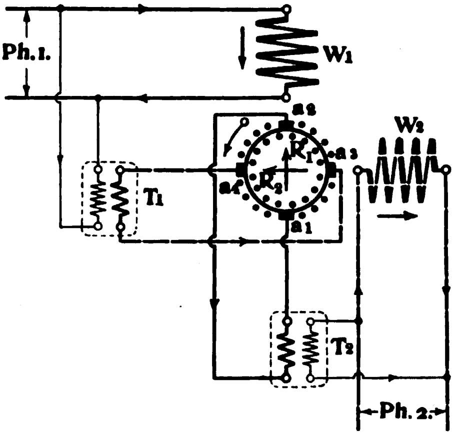

FIG. 42—COMPENSATED TWO-PHASE SHUNT INDUCTION COMMUTATOR MOTOR (WITH STATOR-EXCITATION)

Two-Phase Shunt Induction-Conduction (Commutator) *Motor* (with Stator-Excitation). Fig. 43.

This differs from the foregoing motor in that an auxiliary e.m.f. in phase with the induced working e.m.f. is conductively introduced into each of the rotor working circuits by means of the transformers T_1 and T_2. By this means the effective working e.m.f. in each rotor axis can be adjusted independently of the transformer fluxes and the speed of the machine made to differ from the synchronous. These *speed-regulating* e.m.fs. should of course, either assist the induced working e.m.fs. in both axes or oppose them in both.

Two-Phase Shunt Induction Motor (with Stator-Excitation) Fig. 44.

This machine is the squirrel cage equivalent of the commutator motor shown in Fig. 41, and stands in the same relation to it as does Fig. 39 to Fig. 34.

Compensated Two-Phase Shunt Induction Motor (with Stator-Excitation). Fig. 45.

This is a combination of the compensated commutator motor of Fig. 42 with the squirrel cage motor of Fig. 44. The transformer in each axis has two secondaries with differing impedances, that of the squirrel cage is adjusted automatically and is beyond the control of the operator, that of the commuted winding is under control. The current in the first can never lead the working e.m.f. impressed on it. The current in the second can be made to lead the working e.m.f. impressed on the commuted winding. The secondary with the lower impedance, *i.e.*, with the commuted winding, will carry the greater number of ampere-turns. Unity or leading power factor can only be obtained by causing the current in each axis of the commuted winding to lead the induced working e.m.f. in that axis. The stator windings in all these machines should be distributed, and the stator should have no defined polar projections.

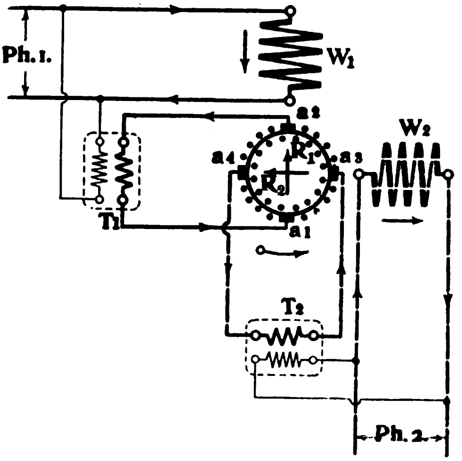

FIG. 43—TWO-PHASE SHUNT INDUCTION-CONDUCTION (COMMUTATOR) MOTOR (WITH STATOR-EXCITATION)

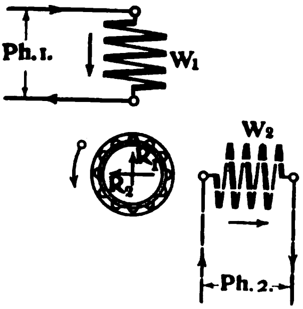

FIG. 44 — TWO-PHASE SHUNT INDUCTION MOTOR (WITH STATOR-EXCITATION)

Neutralized Two-Phase Shunt Conduction (Commutator) *Motor* (with Stator-Excitation). Fig. 46.

Working energy is conductively conveyed to the rotor from phase 1 along one axis, and from phase 2 along an axis displaced by 90 electrical degrees from the first. The rotor ampere-turns, or the reaction fluxes R_1 R_2 thus set up in each axis, are conductively neutralized by means of the stator windings N_1 and N_2. The motor field winding F_1 located coaxially with the rotor circuit connnected to phase 1, is fed from phase 1. The motor field winding F_2 displaced by 90 electrical degrees from F_1, is fed from phase 2. The motor flux set up by the field winding connected across one phase cooperates to produce one half the motor torque with the rotor ampere-turns produced by the other phase, and *vice versa.* Rotation of the rotor conductors in the rotor leakage flux in one axis generates in the other a speed e.m.f. which reduces the impedance of the working circuit of this other axis, and *vice versa.* Since working and exciting currents are independent of each other, the machine must have a shunt characteristic. This motor is not self-compensating. Armature and field circuits being quite independent, the speed of this machine can be set to any desired value. No defined polar projections should be used, and the neutralizing windings should be distributed so as to follow the distribution of the ampere-turns in the corresponding rotor axis.

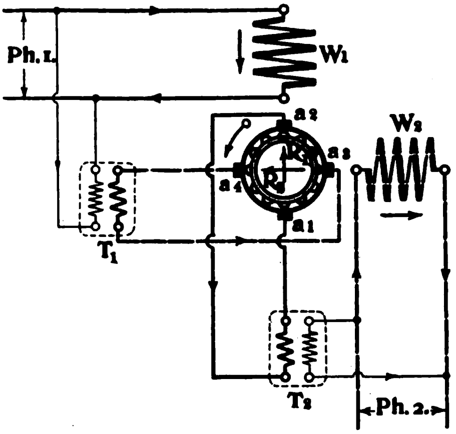

FIG. 45—COMPENSATED TWO-PHASE SHUNT INDUCTION MOTOR (WITH STATOR-EXCITATION)

Neutralized and Compensated Two-Phase Shunt Conduction (Commutator) *Motor* (with Stator-Excitation). Fig. 47.

This motor differs from the foregoing one in that two e.m.fs. are impressed on each of the field windings F_1 and F_2. To the motor flux producing e.m.f. impressed on F_1 and derived from phase 1, is added a compensating e.m.f. derived from phase 2 by means of the transformer T_2 and adjusted to improve

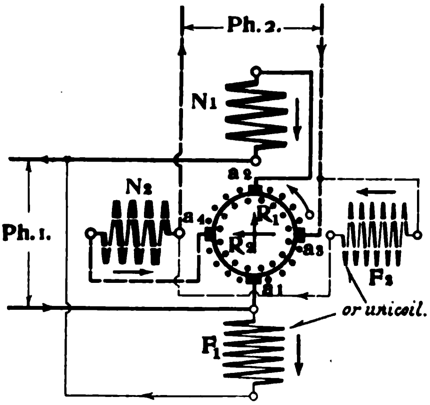

FIG. 46—NEUTRALIZED TWO-PHASE SHUNT CONDUCTION (COMMUTATOR) MOTOR (WITH STATOR EXCITATION)

the power factor in the rotor circuit fed from phase 2. To the motor flux producing e.m.f. impressed on F_2 and derived from phase 2, is added a compensating e.m.f. derived from phase 1

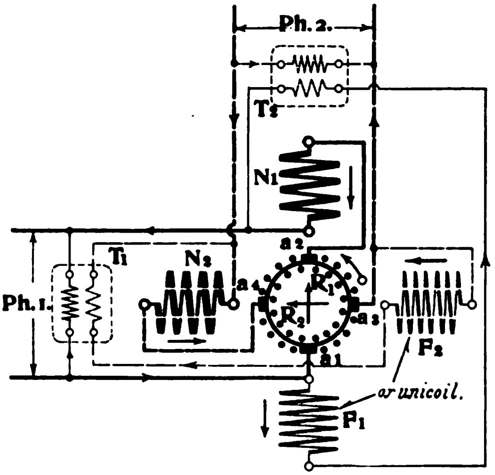

FIG. 47—NEUTRALIZED AND COMPENSATED TWO-PHASE SHUNT CONDUCTION (COMMUTATOR) MOTOR (WITH STATOR-EXCITATION)

by way of the transformer T_1 and adjusted to improve the power factor in the rotor circuit fed from phase 1. In all other respects this machine is identical with that shown in Fig. 46.

REMARKS

It is believed that all the principal forms of alternating-current motors have been classified; if any have been omitted, it is due to inadvertance. The term "repulsion motor" has not been applied to any one of the machines dealt with. The reason is that the author does not know the definition of this term as applied to motors. and is quite sure that the machine to which it was first applied, in 1887, does not operate by virtue of any "repulsion" effect or phenomenon as understood from the year 1820 to the present day. This matter was discussed at some length in a series of articles which appeared in *The Electrican* (London) in 1906, and which have since been reprinted in book form.* Intervening years having only served to confirm the conclusions then arrived at, some of the statements then made, are now repeated.

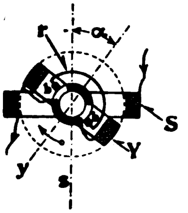

FIG. 48

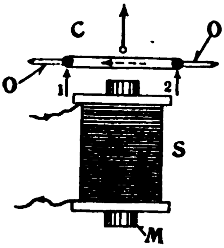

FIG. 49

The term "repulsion motor" is first found in Elihu Thomson's U. S. Patent No. 363,185 of 1887. The form of Thomson's motor as described and illustrated in that specification, is shown in Fig. 48. Within the stationary coil S is mounted a pivoted coil Y, the two ends of which are each connected to a segment of a commutator. These segments are diametrically disposed, and are insulated from each other; brushes b b short-circuited by the short conductor r, bear on these segments. Each segment extends for this two-pole motor over a little less than one quarter of the periphery. When the two coils are concentric, *i.e.*, when the axes y and s coincide, and S is connected to an alternating-current supply, there is no torque even if Y is short circuited, and although a heavy current will under such conditions be induced in that coil. When Y is at right angles to S, *i.e.*, when the axes y and s are perpendicular to each other, there is no torque and no current in Y even if short circuited. In the intermediate positions, *i.e.*, for any values of α between 0 and 90 degrees, a torque will be exerted in the direction shown by the arrow.

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*The Classification of A. C. Motors, by V. A. Fynn. "The Electrician" Printing & Publishing Co., ltd., London.

Among the experiments described in the specification referred to as having led up to the motor shown in Fig. 48, is that illustrated in Fig. 49, where a coil S, connected to an alternating supply and having an iron core, is said to exert a "repelling" effect on a closed coil C disposed in a plane parallel to the convolutions of the coil S and shown in section in Fig. 49. This statement is, of course, perfectly correct, and it is evident that it is the effect to which it refers that led the inventor to apply the term "repulsion motor" to the machine shown in Fig. 48. But the special conditions under which coil C in Fig. 49 is repelled by coil S do not obtain in the motor shown in Fig. 48. In Fig. 49 the "repelling" effect exerted on coil C is of the same direction and magnitude all along the circumference of the coil, as indicated by the small arrows 1 and 2, with the result that coil C will move away from coil *S while keeping parallel to it.* If coil C were pivoted on an axis O passing through its center, and parallel to the convolutions of S, there would be absolutely no tendency for that coil to rotate, but the "repulsion" effect would tend to bend the shaft and the coil. When in Fig. 48 the convolutions of coil Y are parallel to those of S, that is, when the axes y and s coincide—reproducing in this figure as nearly as they can be reproduced, the conditions obtaining in figure 49—then there is and can be no rotation between coils Y and S, but *there is* "repulsion" between the two, owing to which, coil S tends to expand while coil Y tends to contract. The only "repulsion" effect present in the machine shown in Fig. 48, contributes nothing to the rotation of the free member and merely tends to destroy the apparatus.

As a matter of fact the effect illustrated in Fig. 49 is nothing else but that discovered in 1820 by Ampere, and which he summed up somewhat as follows: parallel circuits "attract" each other if traversed by currents flowing in the same direction, and "repel" each other if traversed by currents flowing in opposite directions. This rule applies to a special case of that electrodynamic action which is illustrated in Fig. 50 and which forms the basis of every dynamo or motor whether of the continuous or of the alternating type. A conductor, A, through which a current flows, for instance, upwards through the paper, as indicated by dot, when immersed in a field *F* directed from top to bottom of the paper, will tend to move to the right. Ampere's rule is illustrated in Figs. 51 and 52, which show respectively the "attraction" and the "repulsion" of parallel circuits. The rule illustrated in Fig. 50, when applied to Figs. 51 and 52, explains this behavior, it being only necessary to remember that if in Fig. 50 the direction of the current through *A* or the direction of the field *F* is changed, then the direction of the torque exerted on *A* will be reversed. Taking Fig. 52 we have the current in conductor *A* producing a field of the direction indicated by the full concentric lines, these lines cut conductor *B*, and according to Fig. 50 this conductor *B* will move to the right; similarly the field produced by *B* (dotted lines) acting on *A* will cause the latter to move to the left, hence the "repulsion." Ampere very correctly restricted his rule to *parallel circuits*, and the author can see no reason for altering this now, by describing as "repulsion" the effect responsible for the operation of a particular type of single-phase motor in which there are no interacting parallel circuits.

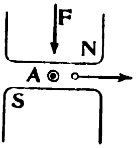

FIG. 50

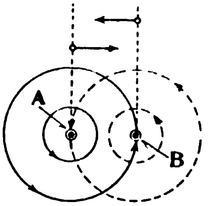

FIG. 51

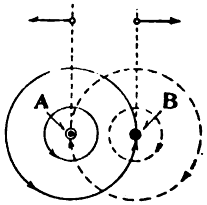

FIG. 52

Of course Ampere's rule holds good for alternating currents as well as for continuous currents; in the former case, however, the magnitude of the "repulsion" or "attraction" also depends on the relative phase of the currents in the two conductors, just as the torque exerted on *A* in the more general case of Fig. 50 also depends on the relative phase relation between the field *F* and the current in *A*. One true example of the application of Ampere's "repulsion" effect in alternating-current practise is to be found in the constant-current transformer with movable secondary coil, one form of which is shown in Fig. 49. In this figure, one component of the current in coil *S* goes to excite the field *M* which conveys the secondary current into coil *Y* by induction; the other component is equal and opposed to that secondary current. The secondary current in *Y* and the component in *S* neutralizing the effect of that secondary current, are of opposite phase, which is equivalent to the same phase but opposite direction, and are responsible for the major part of the " repulsion" effect.

The operation of the motor in Fig. 48, like that of any other electrodynamic motor, is due to the electrodynamic action illustrated in Fig. 50, but not to the special case of same discovered and characterized by Ampere.

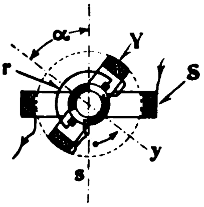

FIG. 53

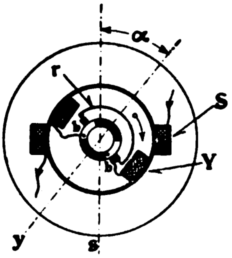

FIG. 54

Returning to the consideration of Thomson's original motor, shown in Fig. 48, it is clear that its operation will not be altered in principle, if the brushes are displaced in the manner shown in Fig. 53; the direction of rotation will, however, be reversed. The principle of operation will also remain the same if the coils *S* and *Y* are embedded in laminations, as shown in Fig. 54. Nor will the principle be changed if the single coil *Y* is replaced by a continuous commuted winding such as shown in Fig. 55, individual coils of which are short circuited by means of the independent brushes b_1 b_2. Fig. 55 shows what may be described as the modern form of rotor for the original Elihu Thomson motor. Figure 56 only differs from Fig. 55 in that the two brushes

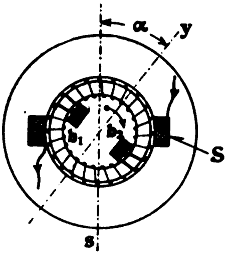

FIG. 55

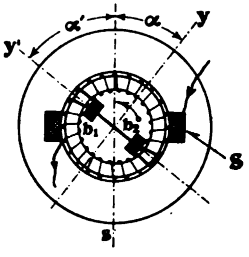

FIG. 56

b_1 b_2 are also interconnected outside of the rotor winding. The brushes of this machine, which is described in U. S. Patent No. 389,352 of 1888, short circuit individual coils of the commuted winding on the rotor in exactly the manner shown in the Thomson motor of Fig. 55, but the machine nevertheless revolves in the *opposite* direction, for the reason that a greater and opposite torque is produced by the rest of the commuted winding which is short circuited by the external interconnection between the brushes b_1 b_2. The turns short circuited by this external interconnection are equivalent to a single coil on the rotor with the axis y' displaced by the angle α' from the axis s of the stator winding S. The motor shown in Fig. 56 may in fact be said to operate in spite of the arrangement originally relied upon by Thomson.

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ECONOMIC OPERATION OF ELECTRIC OVENS

BY PERCY WILCOX GUMAER

Abstract of Paper

The energy losses in an electric oven may be divided into radiation and convection loss, preheating loss and the loss due to opening the oven door. Each of these losses was determined for several electric ovens and their effect on the cost of the cooking of various articles of food is discussed.

With cheap fuels and inefficient stoves it matters little at what temperature a particular article of food is cooked if the results are satisfactory. With electric cooking, however, it is often several cents cheaper to cook an article of food at a particular temperature; for instance, with electricity at $.05 per kw-hr. it is at least $.02 cheaper to roast beef at 120 deg. cent. than at 180 deg.

The results of the experiments performed indicate that for each article of food there is a particular time and temperature for which the cooking can be satisfactorily performed with a minimum amount of energy.

The problem of the engineer in the further development of electric cooking is to design practical cooking devices in which the temperature can be accurately regulated with a minimum of attention on the part of the housewife and thus co-operate with the domestic scientist in the inauguration of truly scientific cooking.

Introduction

As THE use of electricity has been extended to new fields of endeavor it has been the province of the electrical engineer to invade these fields with the purpose of studying the processes and developing better apparatus. The first step has usually been to replace with electricity the former source of energy, keeping much of the old type of apparatus. After a detailed study has been made of the requirements, however, new apparatus is usually developed which incorporates to a greater extent the advantages of the new source of energy.

The first electric ovens were constructed by replacing the burners of a gas oven with electric heating coils. Since the first electric ovens were made there has been considerable improvement in the design and construction of the electric oven. This development has resulted in a more reliable piece of apparatus and a lower operating cost, but practically no study has been

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Manuscript of this paper was received February 4, 1915.

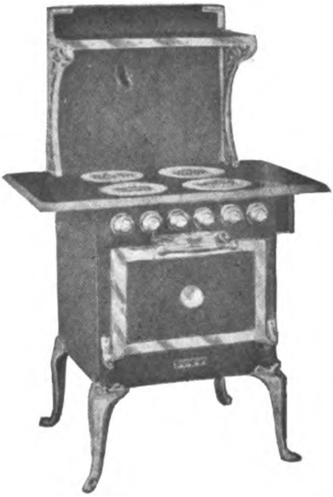
made of the proper conditions for cooking food which make for greater convenience and economy of operation. The present stage in the development of electric cooking might be compared to the conditions which would have obtained, if all the progress in electric lighting had resulted only in increasing the life and efficiency of the electric light without adding in any way to our knowledge of the proper arrangement and character of lights to use under various conditions. Before the advent of the electric light very little was known of the principles of illumination so as to obtain the greatest efficiency of operation. Before the introduction of electric cooking and even today very little is known of the proper conditions of time and temperature to use in cooking various articles of food so as to secure the greatest efficiency. With cheap fuels and inefficient stoves it makes little difference whether a particular article of food is cooked for half an hour at 200 deg. cent. or for one hour at 150 deg. cent. as long as the quality is satisfactory. With electric cooking, however, the temperature at which food is cooked makes a considerable difference in the cost of the cooking.

It is the purpose of this article to study the operation and design of electric ovens, with the view of determining some of the factors which will increase the popularity and economy of electric cooking.

APPARATUS USED

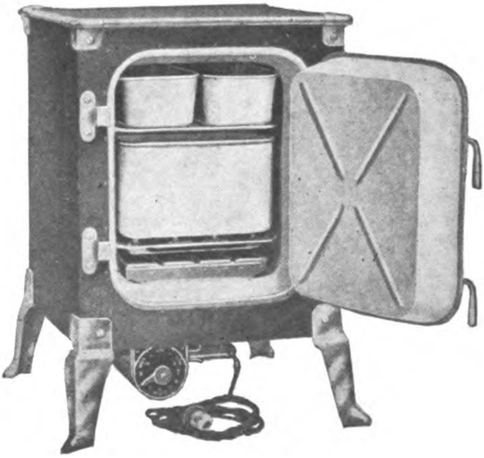
In order to determine the losses of energy in electric cooking and the best methods of preparing various articles of food in electric ovens, tests were made on three commercial ovens and an experimental oven. Each commercial oven was selected as representing a general type of electric oven in use for domestic cooking.

Oven No. 1, as shown in Fig. 1, is a large range suitable for a good size family. The inside dimensions of the oven are 12 in. by 12 in. by 18 in. Two heating units are used, one in the top and one in the bottom of the oven. Each unit consists of two heating coils controlled from a snap switch on the front of the oven so as to consume 220, 440, or 880 watts. From one to two inches of mineral wool is used as heat insulation. The outside surface of the oven is blued steel with nickeled legs and trimmings. The oven door is 12 by 18 inches and 1.5 in. thick. It fits tightly and clamps securely in place when shut. Three heating units are also placed on top of the stove for the cooking which is not done in the oven. Fig. 2 is a cross-section of the



[GUMAER]

FIG. 1—OVEN NO. 1.



GUMAER

FIG. 3—OVEN NO. 2.

oven through the center showing the position of the heating coils and the thermo-couple used to measure the temperature.

Oven No. 2, as shown in Fig. 3, is a small well insulated oven suitable for a small or medium size family. The inside dimensions of the oven are 9.5 in. wide, 10 in. deep, and 12 in. high. The inside finish is seamless drawn aluminum and the outside is blued steel with nickeled trimmings. Two and one-half inches of mineral wool is used for heat insulation. An iron-clad heating element is placed in the bottom of the oven. The heating element consumes 500 watts when connected to a 110 volt circuit. The heat cannot be turned partly off as there is only one heating element. There is no heating unit in the top of the oven. Underneath the oven is an automatic temperature control which may be set at various values by means of a dial. The dial is graduated in arbitrary numbers from one to eleven. When the handle of the dial is set at a given number a thermostat will open the circuit of the heating element as soon as the inside of the oven has reached a certain temperature. As the oven cools the thermostat must be reset by hand by pushing the handle of the dial. Fig. 4 is a cross-section of the oven through the center showing the position of the heating coil and the thermo-couples.

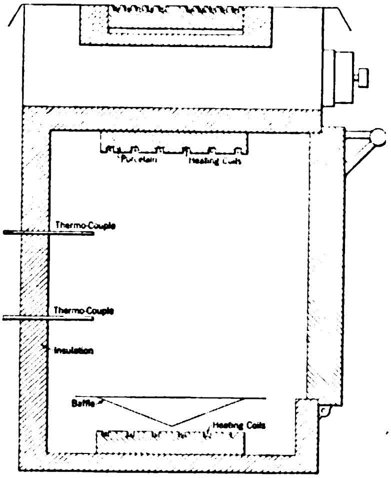


Fig. 2—Cross Section of Oven No. 1

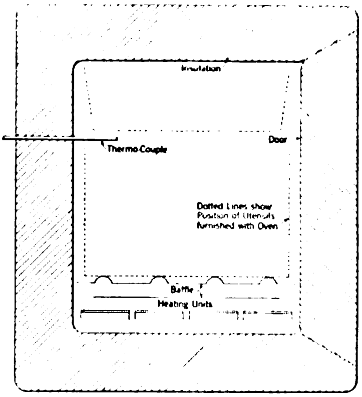


Fig. 4—Cross-Section of Oven No. 2

Oven No. 3 is one of the well known makes of fireless cookers with a heating element placed underneath the inner lining. The inside dimensions are 10.5 in. deep and 12.5 in. diameter. The inside lining is seamless drawn aluminum and the outside finish is varnished oak. The sides and bottom are insulated with powdered kieselguhr while the cover is insulated with granulated cork. Fig. 5 is a cross-section of the oven showing the position of the thermo-couple and heating coil. The oven uses 500 watts at 110 volts. There is no method of turning the oven partly off.

Oven No. 4 was constructed by the author so as to obtain data on the characteristics of an especially well insulated oven. The inside dimensions were the same as oven No. 2. A 220-, 440-, 880-watt heating unit was placed in the bottom of the oven and a 440-watt heating unit was placed in the top as shown in Fig. 6. Sheet iron was used for the inside lining of the oven. A four-in. layer of a commercial brand of diatominous insulating brick was used for insulation. Later four in. of cork board was added as shown in the drawing. This was put on with cement and no outside covering was used except on the front and the door which were covered with wood.

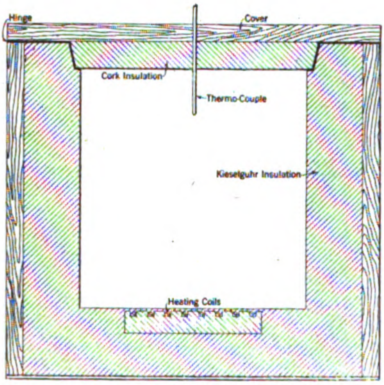


FIG. 5—CROSS-SECTION OF OVEN NO. 3

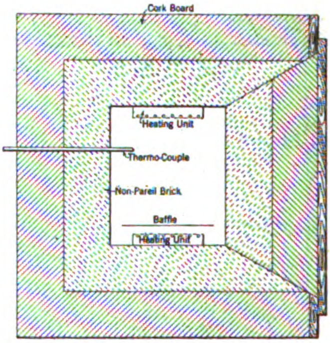


FIG. 6—CROSS-SECTION OF OVEN NO. 4

The temperature of the ovens was measured by means of copper-constantan thermo-couples. An indicating galvanometer and a recording galvanometer were used to determine the e.m.f. of the thermo-couples. The recording galvanometer traced a curve by intermittent contact on a circular smoked chart.

Both the indicating and the recording galvanometer were calibrated for the copper-constantan thermo-couples by means of mercury thermometers certified by the Bureau of Standards. The calibration was made by slowly heating the thermo-couple and thermometer in an oil bath.

In the oven the wires of the thermo-couple were enclosed in a glass tube and separated by mica. Outside the oven they were enclosed in rubber tubing. The cold junction was kept at zero degrees cent. by immersion in ice water. Two thermo-couples were used in series so that a larger deflection was obtained and as the hot junctions were in different parts of the oven the temperature recorded was a mean of the two values.

In oven No. 1 an extra thermo-couple was inserted for measuring the internal temperature of food. The wires entered the oven through two glass bushings and were left bare except for a three-in. glass tube at the end which was inserted in the food.

THE PURPOSE OF COOKING

Before discussing the problems which must be solved before an ideal electric cooking device can be perfected, a word about the purpose of cooking foods will not be out of place. Briefly stated, the objects of cooking food are: (1) to render it more digestible so that the digestive organs can more easily digest and absorb the nutrient parts, (2) to make the food more appetizing by improving its appearance and by developing in it new flavors, (3) to sterilize it so that it will keep longer. The relative importance of each purpose depends upon the article of food which is to be cooked. For example in the cooking of animal foods the improvement of the flavor and the appearance is the most important. The cooking of these foods which are rich in protein actually decreases their digestibility. This is true at least of the chemical processes of digestion, but the increased attractiveness of well cooked meat may render it indirectly more digestible by causing a greater flow of the digestive juices.

The effect of heat on the protein of foods is to coagulate it. This change occurs at the comparatively low temperature of 75 deg. cent. If the temperature is increased much above this point the protein tends to shrink and harden, and the digestibility of the food is greatly lessened thereby.

The effect of heat on the starch of foods is to make it more digestible. In many vegetables and unground cereals the starch grains are enclosed in woody, fibrous, or cellulose walls which are but slightly affected by the digestive juices. The effect of cooking by the application of moist heat is to cause the starch grains to swell and finally to rupture the cellulose walls. The starch is then said to be gelatinized. This process occurs at temperatures much below the boiling point of water. The investigations of the U. S. Department of Agriculture show that starch cooked below the boiling point is as easy to digest as starch that has been boiled.[1]

The fat of foods is practically unaffected chemically by the degree of heat used in cooking.[2]

The ideal preparation of food for human use requires that the nutriment which it contains shall be utilized to the fullest extent. Not only should the food be in such a state that the digestive juices can best act on it, but these digestive juices should be properly stimulated to do their work, by improving the taste or flavor of the food.

The present day problem is to determine the methods of cooking which will yield the most in nutrition and flavor with a minimum expenditure of fuel and labor. The solution of this problem will require careful research by the physiological-chemist, the domestic scientist, and the manufacturer of cooking apparatus. Taking into consideration the results of experiments on the digestibility of foods cooked in various ways, the problem of the domestic scientist is to definitely determine the range of temperatures and the time of cooking at each temperature for all classes of food. Effects of quality and proportion of ingredients, size of utensils and other variables must be studied so that definite rules and tables can be worked out giving the most desirable times and temperatures of cooking any article of food.

The problem of the electrical engineer is to determine, from the range of temperatures for cooking any article of food, the particular temperature which is the most economical. He must also perfect an electric cooking apparatus which will maintain the desired temperature with a minimum amount of attention, and which will be low in the first cost and economical in operation.

Losses of Energy in Electric Ovens

During the past century there has been a great advance in the methods of applying heat to food. Each improvement has resulted in less of the heat energy being wasted and in more being absorbed by the food. Each step, from the open fireplace to the coal range, to the gas stove and finally to the electric oven has been marked by the use of more expensive fuel, greater heat efficiency, and better control of the heat.

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[1] U. S. D. A. Bul., No. 202.

[2] U. S. Dept. of Agr. Farm Bul., No. 526, p. 14.

Except in a few localities, for the same number of heat units delivered at the meter, electricity is more expensive than gas or coal. Hence, it is only by studying carefully the most economical features of design and operation of electric cooking apparatus that electricity will be able to compete with gas and coal.

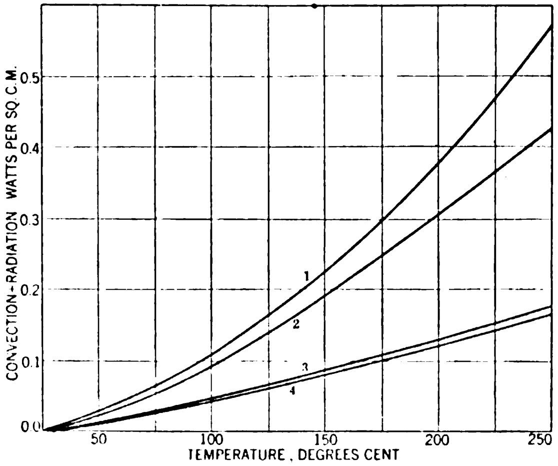

Fig. 7—Total Losses from Heated Surfaces in Air. Convection Loss is for Vertical Surfaces

1. Black body.
2. oxidized copper
3. pure silver
4. Convection only

A study of the heat losses in cooking is, therefore, of considerable importance to the designer of electric cooking apparatus.

Convection and Radiation. If an electric oven is supplied with heat at a constant rate, say 1000 watts, the temperature of the oven will increase rapidly at first and then more slowly until it finally reaches a constant value. From the law of the conservation of energy it follows that if there is no food in the oven the same amount of energy is lost into the room as is supplied by the heating coil. This heat is lost in two ways by convection and by radiation.

The radiation loss consists of waves of energy similar to light waves but of different length. The amount of the energy radiated depends upon the nature of the surface the temperature of the surface and the temperature of the surroundings. It is independent of the shape of the radiating surface. The convection loss, however, depends upon the shape and the position of the surface as well as the temperature of the surface and the surroundings. It is independent of the nature of the surface.

The radiation and convection losses from horizontal and vertical plane surfaces have been determined by Langmuir[3] for various materials. Fig. 7 shows the convection and radiation losses for vertical plane surfaces for temperatures up to 250 deg., the highest used in cooking.

As shown by the curves, the radiation loss from a black body constitutes a large part of the total loss, while the radiation from a polished silver surface forms but a small part of the total loss. For all other surfaces the radiation loss lies between that of a silver surface and a black surface; the convection being the same for all surfaces.

There are two ways in which the heat loss of an electric oven may be reduced. Consider an oven of given inside dimensions built on the plan of an ordinary gas oven, with a black outside surface and no heat insulation. The temperature of the outside surface will be within a few degrees of the temperature of the oven. A large amount of energy will be required to maintain a cooking temperature inside the oven. Since the convection and radiation losses depend on the temperature of the outside surface the losses will be greatly reduced if this temperature can be decreased. If the inner and the outer surface of the oven are separated a few inches and the intervening space filled with a poor conductor of heat such as mineral wool, kieselghur, or poplox, there will be a large drop in temperature between the inner and the outer surfaces, because the heat will be conducted very slowly away from the hot interior.

Suppose that enough heat insulation were introduced to reduce the outside temperature from 200 deg. to 110 deg. cent.; the watts lost per sq. cm. of outside surface would be reduced from 0.37 to 0.12 as shown by the curves of Fig. 7. Stated in another way, the energy required to maintain the inside temperature of the oven at its former value would be reduced from 1000 watts to 325 watts for the same outside surface. For the same inside dimensions, however, the area of the outside will be larger because of the added insulation and hence the energy will be slightly greater than the above value.

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[3] Trans. of Am. Electro-Chem. Soc., Vol. 22, p. 299 (1913).

Another method of reducing the heat losses would be to silver plate the outside of the oven. The heat loss would then be decreased from 0.37 watts per sq. cm. to 0.13, or the energy required to maintain the same inside temperature would be reduced from 1000 watts to 350 watts. By a combination of the two methods the input of the oven for the required internal temperature would be reduced from 1000 watts to 165 watts.

To silver plate the outside surface of an electric oven would be too expensive to be practical, but there are cheaper surfaces which radiate a small amount of energy compared to the ordinary black oven. A white enameled surface for instance would be much more efficient than the black surface. A place in which nickel plating could be used to good advantage would be around the edge of the oven door. Because of the good heat conductivity of the metal which connects the inner and outer surfaces of the oven around the door, the outside temperature of the oven is considerably higher around the edge of the door than elsewhere on the outside. If the nickeled plating now used on the legs and the corners of the stoves were put around the edge of the door, it would help to decrease the losses and the cost of the oven would be no greater.

The heat losses from an electric oven can be easily determined by measuring the energy input and the temperature after the equilibrium conditions are established. The heat losses for the ovens tested were obtained in the following manner: A thermo-couple inside the oven was connected to a recording galvanometer. A given amount of energy was turned on so that the temperature of the oven increased, until finally, the heat lost equalled the energy measured by the wattmeter. The tests were continued until the oven temperature had remained constant for at least two hours. This was repeated for other values of energy input and curves were plotted between oven temperature and watts input as shown in Fig. 8. It will be noticed that the curves obtained are straight lines, all cutting the temperature axis at room temperature. Although very exact measurements might show a slight upward tendency at higher temperatures, the present results with a maximum error of 2 per cent are sufficient for practical use.

Since the character of the surface and the outside area will remain constant for a particular oven the above curves showing the relation between oven temperature and the energy lost by radiation and convection should be similar to the curves shown by Langmuir (Fig. 7). The apparent discrepancy can be accounted for in that the greatest outside temperature of the ovens tested was only 80 deg. cent. and below that temperature Langmuir's curves do not depart perceptibly from a straight line.

As will be shown later, the temperature energy curves of Fig. 8 are very useful in comparing the economy of various ovens for the cooking of any article of food. Since one point of the curve will be zero energy at room temperature, only one determination is necessary to plot the curve for any particular oven. For a given room temperature, measure the watts input and the temperature of the oven after it has become constant.

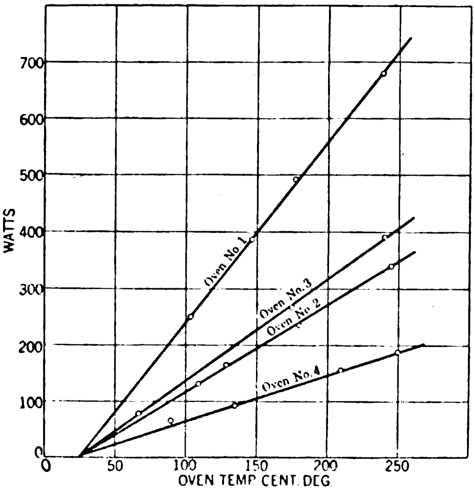

FIG. 8—ENERGY REQUIRED TO MAINTAIN OVENS AT CONSTANT TEMPERATURE

A straight line between this point and a point on the temperature axis will give the heat lost from the oven at any oven temperature. These results give the energy lost through the insulation and the metal around the edge of the door.

Preheating. The heat losses of an electric oven may be separated into the losses occurring before and after the food is inserted in the oven. In many kinds of cooking such as baking biscuits and cake the food must be placed in a hot oven as soon as it is prepared. Since for domestic purposes an oven is never used continuously, it cools off during the interval in which it is idle. Before it can be used again the inside of the oven and the enclosed air must be heated up to a cooking temperature. This operation is called preheating. The amount of energy required to preheat an oven to the desired temperature depends on the insulation of the oven, its size and the thermal capacity of the inside, and the size of the heating coils. The amount of energy required to preheat the ovens tested was obtained by taking simultaneous readings of the temperature and the watt hour meter. Fig. 9 shows the results obtained. It will be noticed that although oven No. 4 was better insulated than oven No. 2 it required more energy for the preheating. This was probably due to the greater heat capacity of the inside lining and the insulation. The effect of too small a heating coil is shown for the curve for oven No. 3. For high temperatures, the energy required for preheating this oven is altogether too large for the size of the oven. The time required for the oven to reach a baking temperature of 250 deg. cent was 2.5 hours. In order that the electric energy for preheating shall be as small as possible the inner parts of the oven should have as small heat capacity as is practical and the heating coils should be large enough to

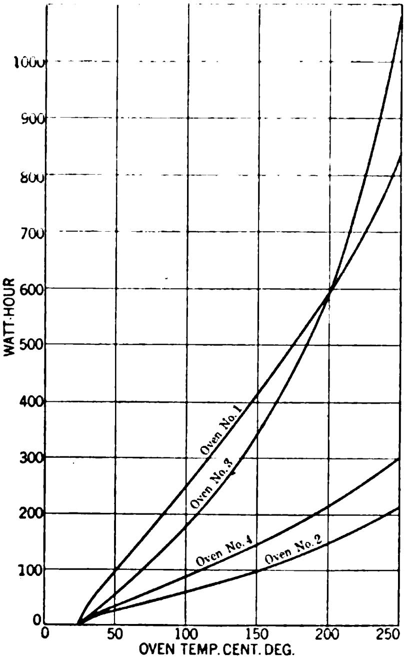

FIG. 9—ENERGY REQUIRED TO PREHEAT OVENS

heat the oven to the desired temperature in a fairly short time. If the time required for the oven to reach the desired cooking temperature is excessive not only is there a delay in the cooking operation but a larger amount of the energy is lost into the room by radiation and convection during the preheating

Heat Loss when the Oven Door is Opened. In preparing food which cannot be placed in a cold oven and heated gradually, there is a loss of heat when the oven door is opened. The amount of this loss and the fall of temperature of the oven were determined for oven No 1 as follows: the energy input was measured by means of a watt meter and was kept constant for each test. The temperature of the oven was obtained by means of a thermocouple and the recording galvanometer. The variation of the temperature when the oven door was opened for 15 sec. at 3 min. intervals was determined. The average temperature gradually changes and finally reaches a constant value. A curve plotted between these average temperatures and the energy

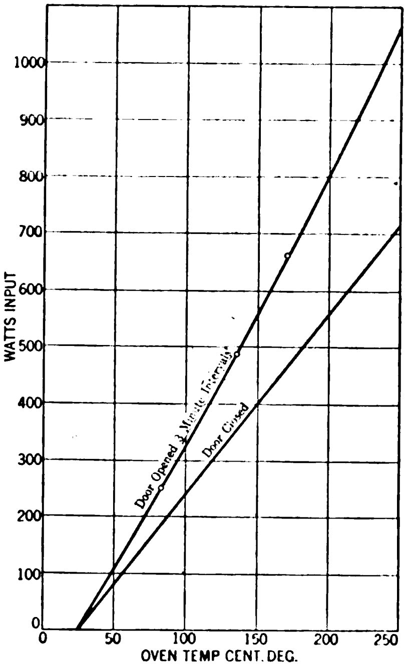

FIG. 10—ENERGY REQUIRED TO MAINTAIN CONSTANT AVERAGE TEMPERATURE OF OVEN No. 1, DOOR OPENED 15 SEC., 3-MIN. INTERVALS

input is shown in Fig. 10. The difference between the ordinates of this curve and the similar curve obtained with the door closed evidently represents the energy lost by opening the door. From these values the energy lost each time the door is opened is readily calculated. Fig. 11 shows the watt-hours lost each time the door of oven No. 1 is opened for 15 sec. and the fall in temperature of the oven when the door is opened at different oven temperatures.

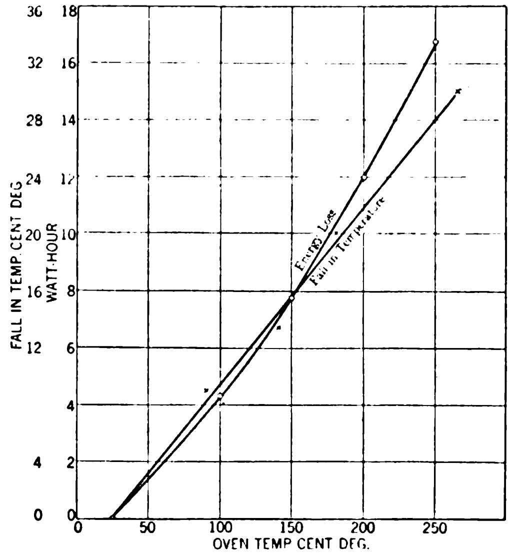

Fig. 11—Effect of Opening Door of Oven No. 1 for 15 sec., Upon Energy Lost and Fall in Temperature of the Oven

Experiments in Roasting Beef

Meat may be cooked by any of the methods in common use for the cooking of food of which the most important are: roasting, baking, frying, broiling, stewing, and boiling. Until recently there has been little known concerning the scientific principles of cooking meat. Since there has been no uniformity in the processes of cooking the terms vary widely in their meaning. Roasting which was formerly applied to cooking over red hot coals is now used synonymously with baking or cooking in an oven by means of dry heat. Stewing and boiling have not been clearly defined. Both apply to the cooking of meat when immersed in hot water. The present tendency in scientific literature is to use the term boiling when meat is cooked in hot water at any temperature and to specify the exact temperature used. Broiling and frying will not be discussed in this paper, as it is impractical to utilize the advantages of an insulated electric oven for preparing the meat by either method.

There is a wide diversity of tastes in regard to the proper degree of cooking of a meat roast. Some people prefer that meat should be heated only enough to slightly change the color of the interior of the meat while others prefer the meat to be cooked until every trace of the pink color has disappeared. This difference in taste causes a corresponding variation in the meaning of the terms used to describe the degree to which meat shall be cooked. The meat which one person calls rare is medium rare to another, and oftentimes meat which is actually raw is served as rare.

In this paper the terms rare, medium rare, and well done are used to indicate the same degree of cooking as defined by Miss E. C. Sprague.[4] The definitions are as follows:

> Rare or underdone meat. In the center of a rare roast the dull bluish red characteristic of raw meat has changed into the bright rose red of rare meat. This shades into a lighter pink toward the outer portions and changes into a dark gray in the layer immediately underlying the outer brown crust. The ideal standard for rare meat requires that the larger portion shall have heen heated only enough to effect this change to rose red, so that the outer brown crust and the intermediated grey layer shall be as thin as possible. Under these conditions there will be a liberal quantity of bright red juice.
>
> Well done meat. If the cooking is continued for a sufficient length of time, instead of being distended the meat shrinks noticibly. The whole interior is found to have become a brownish gray in color and the juice is scanty and either colorless or slightly yellow. Meat cooked to this degree is said to be well done.
>
> Medium rare meat. A condition between these two extremes is indicated by the term medium rare. In this case sufficient heat has been applied to change the color of the center to a light pink. The gray layer underlying the crust has therefore, extended considerably towards the center. The free juice is smaller in quantity and lighter in color than in the rare meat.

The experiments of Grindly and Sprague have demonstrated that beef can be satisfactorily roasted at an oven temperature anywhere between 100 deg. and 200 deg. cent. A beef roast prepared at any temperature within this interval was found to be well browned and attractive looking. No difference was discernible in the tenderness of duplicate roasts cooked at the extremes of temperature. In their opinion, the flavor and juciness of the meat was slightly better at the lower temperatures, whereas at the higher temperatures the drippings were better flavored and larger in quantity.

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[4] University Studies, Univ. of Ill., Vol 2, No. 4, p. 4.

Since a roast of beef can be properly prepared at any temperature between 100 deg. and 200 deg. cent., the most satisfactorily temperature within this interval can be determined only by the consideration of other factors, of which the time of cooking and the cost of cooking are the most important. In order to determine this most economical temperature for roasting a rolled rib roast, a series of experiments were performed.

Twenty-two roasts consisting of the third and fourth standing rib cuts, were obtained from the local market. The meat was freed from bone and tightly rolled and secured with wooden skewers. Samples were roasted at 100, 120, 140, 160 and 180 deg. cent. The time required for the cooking and the amount of energy used at each oven temperature was measured. From these values the most economical temperature for roasting a rolled roast was determined.

In order to get uniform results in the degree of cooking the meat, it was necessary to decide on a rather exact method of determining when the meat was sufficiently cooked. As mentioned before the aim in cooking meat is not to increase its digestibility but to improve its flavor and appearance. This is accomplished by decomposing the red coloring matter called oxyhaemoglobin which removes the raw appearance of the meat. The inside of the roast should be heated sufficiently to accomplish this without overcoagulating the proteids or removing from the meat those substances which tend to become soluble or volatile upon the application of heat.

Grindly and Sprague[5] found that if the inner temperature of a roast is between 55 and 65 deg. cent. the meat will be rare, if it is between 65 and 70 deg. cent. it will be medium rare, and if between 70 and 80 deg. cent. it will be well done. In order to secure as much uniformity as possible in the results, a definite temperature rather than a range of temperatures was taken as the indication of when the meat was sufficiently cooked: 55 deg. cent. was used for rare, 65 deg. for medium rare and 75 deg. for well done.

It is not always possible to obtain the exact inner temperature to a degree, because if the roast is taken out of the oven when the inner portion of the meat is at some particular temperature say 60 deg. this temperature will not begin to decrease immediately, but will first increase several degrees before it begins to decrease. This increase of temperature after the roast is removed from the oven depends upon the temperature of the oven in which the meat is cooked, being greater for a high oven temperature.

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[5] Univ. of Ill. Bul., V. 2, p. 290.

A copper-constantan thermo-couple was used to measure the temperature inside the roasts. The thermo-couple was connected to the recording galvanometer which gave a continuous record of the temperature inside the roast.

The authorities on meat cooking recommend that a roast be cooked for the first 10 or 15 minutes at an oven temperature of 250 deg. cent. so as to sear the outside of the meat. The theory is that the coagulation of the outer surfaces of the meat will act as a seal to keep in the meat juices and volatile flavors. A consideration of the heating curves of the electric ovens discussed in the first part of this paper, shows that to heat an oven up to 250 deg. cent. and to keep it there for 15 minutes will increase the cost of the electricity for roasting the meat about 50 per cent. In order to reduce this extra cost of energy another method was tried which proved very successful. Instead of searing the meat in the oven at a high temperature it was seared on the top of the stove or rather by placing the meat in an aluminum dish over an 880-watt heating coil. The current was turned on for three minutes to get the dish quite hot. The meat was then placed in the hot dish and seared for ten minutes, being turned frequently so as to sear all sides.

After searing an incision was made in the roast with a sharp narrow bladed knife, and the thermo-couple was inserted as near as possible in the center of the large muscle of the roast. The roast was then placed in the oven at the desired temperature. Placing the roast in the oven lowered the temp. from 10 to 20 deg. Full current was turned on until the temperature returned to the desired value, after that the temperature was kept constant within 2 deg. cent.

When the temperature inside the roast indicated the meat to be cooked rare, the time and watt-hour readings were recorded. This was also done for medium rare and well done. As soon as the inside temperature indicated the meat to be well done, the roast was taken out of the oven and left on a shelf in front of the oven, the leads of the thermo-couple being long enough so that it could still be left inside the meat. The meat was allowed to stand until the temperature had reached its maximum value. After being weighed and cooled on ice it was cut into and examined.

TABLE IV.

Temp. of oven cent. degrees.	Time of cooking of meat roasts in minutes.			
		Rare		
100	121	122	120	121 Ave.
120	107	89	97	98 "
140	99	76	71	82 "
160	53	71	67	64 "
180	80	58	53	63 "
		Medium Rare.		
100	162	176	170	169 "
120	139	114	124	126 "
140	111	89	106	102 "
160	75	91	86	84 "
180	105	82	75	88 "
				"
		Well done.		
100	241	260	248	250 "
120	177	165	172	171 "
140	151	124	132	136 "
160	164	120	113	112 "
180	135	105	113	118 "

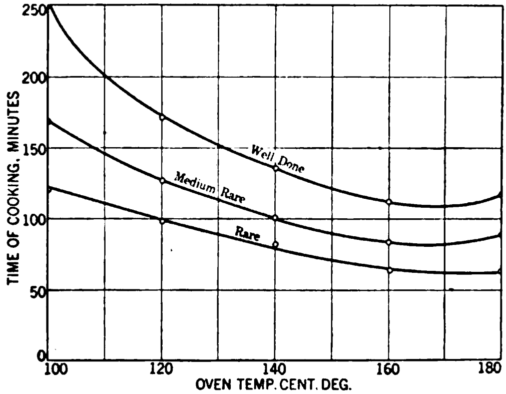

FIG. 12—EFFECT OF OVEN TEMPERATURE ON TIME OF COOKING OF BEEF ROASTS

Table IV gives the time of cooking of the roasts for rare, medium rare, and well done. Fig. 12 shows the average time of cooking plotted against oven temperature. It will be noticed that at an oven temperature of 160 deg. cent. the roasts are cooked in a shorter length of time than at 180 deg. This is probably due to the fact that the slightly charred surface of the meat is a poorer conductor of heat. For the well done roasts the time of cooking increases rather rapidly as the temperature decreases. This is not a disadvantage, however, if the temperature can be obtained automatically without the attention of the cook.

TABLE V.

Temp. of oven cent. degrees.	Weight before cooking grams	Weight after cooking grams	Loss in weight	Per cent loss in weight	Average per cent loss
100	1904	1502	402	21.1	
	1600	1288	312	19.5	
	1760	1392	368	20.9	20.5
120	1580	1270	310	19.6	
	1782	1380	402	22.6	
	1824	1434	390	21.4	21.2
140	1700	1352	348	20.5	
	1900	1492	408	21.5	
	1820	1414	406	22.3	21.4
160	1554	1160	394	25.3	
	1612	1237	375	23.2	
	1566	1182	384	24.5	24.3
180	1628	1220	408	25.1	
	1832	1335	497	27.1	
	1814	1300	514	28.3	26.8
200	1805	1244	561	31.0	31.0

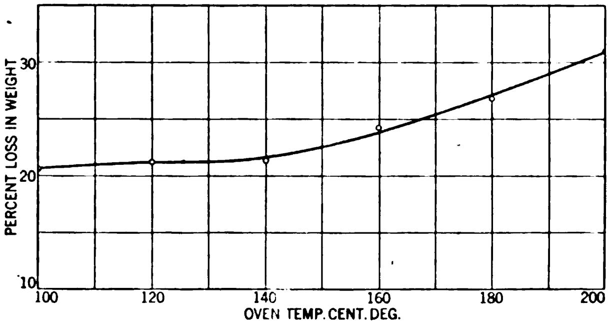

FIG. 13—EFFECT OF OVEN TEMPERATURE ON LOSS IN WEIGHT OF RIB ROAST

Table V gives the weights of the roasts before and after cooking and the per cent loss in weight due to the cooking. The average values of the per cent loss in weight of the roasts in cooking are plotted in Fig. 13. It will be noticed that the per cent loss in weight of the roasts increases with the temperature. The curve shows that as far as the losses in cooking a well done roast are concerned, meat is best when cooked between 100 and 120 deg. cent., or possibly lower.

As the proper facilities were not available no attempt was made to analyze the drippings obtained at the various temperatures to determine the proportion of water, protein and fat. The appearance of the drippings, however, would indicate that there is a larger proportion of fat in the drippings obtained at high oven temperatures than at the low temperatures.

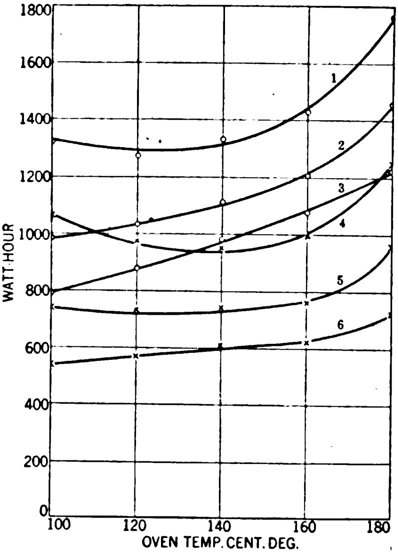

Fig. 14—Energy Required to Roast Beef on Oven No. 1 Starting with Oven Hot and with Oven Cold—Searing, 190 watt-hr. Additional

1. well done roast oven cold
2. med. rare " " "
3. rare " " "
4. well done " " hot
5. med rare " " "
6. rare " " "

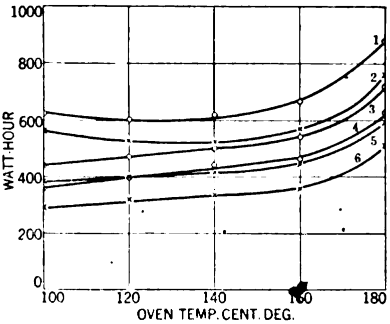

Fig. 15—Energy Required to Roast Beef in Oven No. 2, Starting with Oven Hot and with Oven Cold—Searing, 190 watt-hr. Additional

1. well done roast, oven cold
2. " " " " hot
3. med. rare " " cold
4. rare " " "
5. med. rare " " hot
6. rare " " "

The other important factor which determines the best roasting temperature is the cost of the electricity used. The curves of Fig. 14 and 15 give the energy used in roasting beef in ovens No. 1 and 2 starting with the ovens at the required temperature and starting with the oven at room temperature. The energy used in searing the roasts is not included in the ordinates of these curves, since it was the same in all cases, 190 watt-hr. It will be noticed that for rare roasts 100 deg. is the most economical temperature in each oven; for the medium rare 100 deg. is the most economical except for oven No 1 for which 120 to 140 deg. is the best. The difference in this case is very slight, however, and within the probable error so that 100 deg. could be used economically even here if desired. For the well done roasts there is a decided difference in the cost of cooking the meat at the various oven temperatures. For all the ovens and the most economical temperature for the well done roasts lies between 120 and 140 deg. cent.

It will be noticed that when preheating is included the rare and medium rare curves are much steeper, and that the difference between the cost of preparing a roast at 100 and 180 deg. is greater. For ovens No. 1 and 2, 120 deg. is the most economical temperature for well done roasts. While the cost of electricity at $.05 per kw-hr. for oven No. 1 the difference between the cost of roasting meat at 100 and 180 deg. is $.02 for rare and $.025 for medium rare, and for well done the difference between 120 and 180 deg. is $.025. The saving in the months bill would probably amount to about $.50, depending of course on the number of roasts prepared. It is well worth considering, however, as by observing these economies electric cooking will be able to compete with cheaper fuels.

It will be noticed that the energy required for roasting meat in oven No. 1 is considerably greater than for oven No. 2. This is due partly to the smaller amount of heat insulation used and partly to the larger size of the oven. The oven was much larger than was necessary for cooking a roast of this size. On this account both the radiation and the preheating loss were much greater than in the smaller oven.

An experiment was tried by searing the roasts in the manner recommended by the cook books. The oven was heated to 250 deg. the roast was placed therein, and full current was turned on until the temperature had returned to the desired value. The current was then turned off and the oven allowed to cool down to 100 deg. where it was kept constant during the remainder of the experiment. The energy required to prepare the roasts by both methods is given in the following table:

TABLE VII.

WATT-HOURS USED IN PREPARING ROASTS BY THE TWO METHODS OF SEARING

Searing on top coil.	Remainder of test in oven at 100 deg.	Total.	Total when seared in oven.	Difference.
rare 190	790	880	1950	1070
well done . 190	1325	1515	2580	1065

The saving in energy in favor of searing on top of the stove is surprisingly great, making a difference of $.05 (at $.05 per kw-hr.) in the cost of preparing the roast. This great difference in the energy used by the two methods is due to the fact that when searing the meat in the oven the whole oven has to be heated up to the high temperature of 250 deg.; resulting in large preheating and radiation losses, while by the other method only the heating element the dish and the outside surface of the roast are heated to the high temperatures. The losses are consequently greatly reduced.

BAKING EXPERIMENTS

Owing to a lack of definite information on the time and temperature of baking, a series of experiments were undertaken on the baking of biscuit, bread and sponge cake. The purpose of the experiments was to determine the range of temperatures within which each article of food could be satisfactorily baked and the particular temperature within this interval which was the most economical for the ovens tested.

The method used was to determine the minimum time of baking at several oven temperatures. The experiments at a particular temperature was started at what was thought to be the proper time of baking at that temperature. If the condition of the food was well done and well browned, the time of baking was reduced. This process was repeated until under done samples were obtained. The shortest time of baking which gave satisfactory results was the value taken for that particular temperature. This was repeated for several oven temperatures and curves were plotted between the temperature of the oven and the minimum time of baking. Each sample was carefully weighed before and after baking and the per cent loss of weight determined. The per cent loss of weight obtained at the minimum time of baking was then plotted against the oven temperature. Each point obtained on this curve was the means of three determinations. The experiments were first performed in oven No. 1 and then were checked in the other ovens.

Because of the short time of cooking and the small amount of food used in each sample it was not found possible, as in the meat experiments, to get accurate measurements of the amount of heat absorbed by the food. Consequently the amount of energy used in baking at the various temperatures in each oven was taken at the sum of the losses.

The materials for the baking experiments were furnished by the home economics department of the University of Missouri. The samples were prepared by the members of that department as they were required and were inspected by them after baking.

Fig. 16 shows the minimum time of baking and the per cent loss in weight curves for biscuits. Each sample consisted of six biscuits, each weighing approximately 25 gm.[6]

It will be noticed from the curves that the per cent loss of weight begins to increase very rapidly as the temperature decreases below 200 deg. This increase in the loss of weight for the biscuits at the low temperature indicated that the samples dried out to a greater extent due to the increased time of baking. This was very evident in the character of the biscuits prepared at these temperatures. They were dry and hard and had a heavy crust instead of being crisp and tender. At 200 deg. and above there was no difference discernible in the character of the samples. The range of temperature, therefore, for baking biscuits prepared according to the above recipe is from 200 to 240 deg. cent. Table VIII which gives in detail the results of the biscuit experiments will make clear the method used.

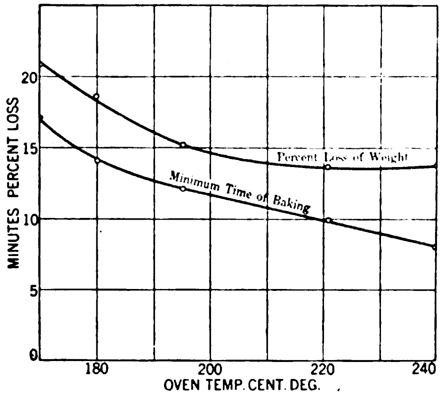

FIG. 16—EFFECT OF OVEN TEMPERATURE ON TIME OF BAKING BISCUITS AND PER CENT LOSS OF WEIGHT

Fig. 17 shows the minimum time of baking and the per cent loss of weight curves for the bread experiments. The loaves averaged 300 gm. in weight and were baked in a tin the dimensions of which were 3 in. by 5 in. by 3 in. deep.[7]

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[6] They were prepared according to the following recipe: 1 cup of flour, 1 tablespoonful of lard, ½ teaspoonful of salt, 2 teaspoonfuls of baking powder, enough milk to make a soft dough.

In the bread experiments the most satisfactory results were obtained above 180 deg. At the lower temperature the crust was hard and thick, due to excessive evaporation of moisture as indicated by the loss in the weight curve. At 240 deg. the outside of the loaf had a tendency to brown over before the inside was thoroughly done. So many factors other than the time and temperature of baking affect the texture and quality of the bread that no attempt was made to accurately score the loaves baked. The quality of the flour, the proportion of the ingredients, and the manipulation before baking[8] all affect the flavor, quality, and texture of the loaf. It may be stated, however, that the range of temperature for baking bread in the above size loaves lies between 180 and 240 deg. cent. As the size of pan used was smaller than is used in the average household, the time required for baking a larger loaf would be somewhat longer.

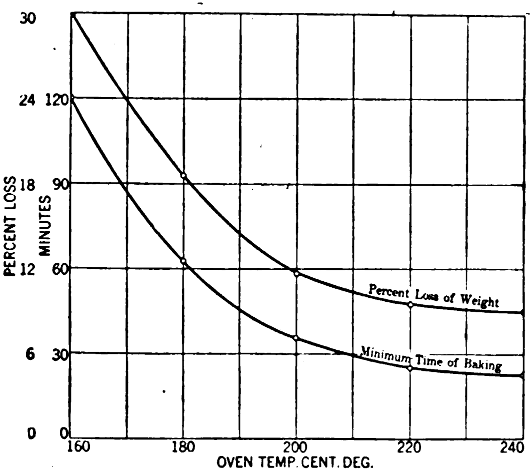

FIG. 17—EFFECT OF OVEN TEMPERATURE ON TIME OF BAKING BREAD AND PER CENT LOSS OF WEIGHT

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[7] The bread was prepared according to the following recipe: ½ cup of water, ½ cup of milk, 1 teaspoonful of lard, ¼ teaspoonful of salt, 1 tablespoonful of sugar, enough hard wheat flour to make a soft dough, yeast.

[8] University of Illinois Bulletin. Volume X, No. 25.

TABLE VIII.

BISCUIT EXPERIMENTS.

Time of baking min.	Oven. temp. cent. deg.	Per cent loss of weight.	Condition of sample.
10	239.5	15.8	well done, well brown
10	239.5	15.5	" " " "
10	240.0	15.9	" " " "
8	239.5	12.9	" " " "
8	239.0	14.9	" " " "
8	240.0	13.0	" " " "
7	241.0	10.1	slightly brown, doughy
7	240.5	10.8	slightly brown, done
7	240.0	10.1	slightly brown, almost done
10	220.0	13.0	well done, well brown
10	221.0	12.9	" " " "
10	221.0	14.4	" " " "
10	220.0	14.3	" " " "
9	220.0	12.9	not brown, doughy
9	221.0	12.2	slightly brown, done
12	195.0	14.2	well done, well brown
12	194.0	15.1	" " " "
12	196.0	15.9	" " " "
10	195.0	8.0	slightly brown, done
10	195.0	7.2	slightly brown, almost done
11	195.0	15.0	well done, slightly brown
11	195.0	13.6	almost done, brown
11	195.5	14.6	almost done, slightly brown
14	180.0	17.8	well done, well brown
14	180.5	19.2	" " " "
14	180.0	18.8	" " " "
13	180.0	13.0	slightly brown, almost done
13	180.0	11.6	well done, well brown
13	180.5	14.3	brown, almost done
15	170.0	17.0	almost done, not brown
15	170.0	16.5	almost done, not brown
15	170.0	16.2	almost done, slightly brown
16	170.5	10.7	done slightly brown
16	170.5	13.3	done, slightly brown
16	169.5	12.7	almost done, slightly brown
17	170.0	20.9	well done, brown
17	170.0	20.2	" " "
17	170.0	21.2	" " "

Fig. 18 shows the minimum time of baking and the per cent loss of weight curves for the sponge cake tests.[9] The loaves averaged 250 gm. in weight and were baked in a tin of the following dimensions: 5.5 in. by 4.2 in. by 2.5 in. deep.

A temperature of 170 deg. is approximately the lowest temperature that should be used for baking sponge cake, as the crust becomes very heavy and thick at the lower temperatures due to the long baking and the large loss of moisture. Because of the larger proportion of liquid in the dough, sponge cake will stand a greater loss of moisture than bread or biscuits. At 200 deg. the loss of moisture was evidently too small as the texture of the crumb was not as good as samples baked at lower temperatures. The range of temperature, therefore, for baking sponge cake lies between 170 and 200 deg. cent.

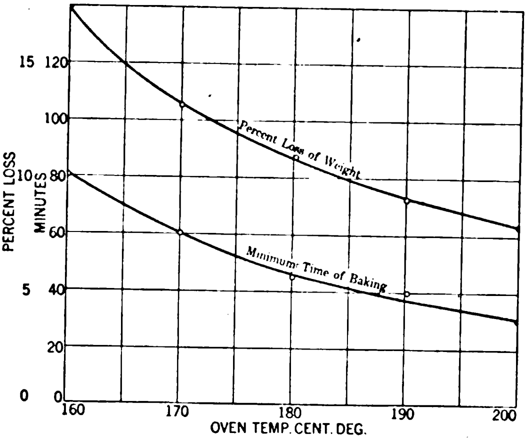

Fig. 18—Effect of Oven Temperature on Time of Baking Sponge Cake and Per Cent Loss of Weight

The curves of Fig. 19 give the energy used in baking biscuits at the various oven temperatures for ovens No. 1, 2, and 4 with and without preheating. The curves show that if biscuits are baked immediately after other food is removed from the oven so that preheating is not necessary the energy required will be very small compared to the amount required if the oven has to be heated up from room temperature to baking temperature. This is especially true of oven No. 1. When the baking is begun with the oven already at the desired temperature, the energy used in baking biscuits is practically the same for all the temperatures tried; but when the oven has to be heated up from room temperature the energy used is considerably less at the lower temperatures. Since the quality of the biscuits baked at temperatures below 200 deg. is not as satisfactory as at higher temperatures, these temperatures are not recommended; 200 deg. is, therefore, the most economical temperature for baking biscuits when preheating is necessary.

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[9] The cake was prepared according to the following recipe: 4 eggs, 1 cup of sugar, 1 cup of flour, 1 tablespoonful of lemon juice.

Because the conditions of baking biscuits satisfactorily are a high temperature for a short time, the greater part of the energy required will be used in preheating. Consequently ovens use for baking biscuits should require as little energy as possible for preheating. This can be accomplished to a certain extent by using as small an oven as is practical.

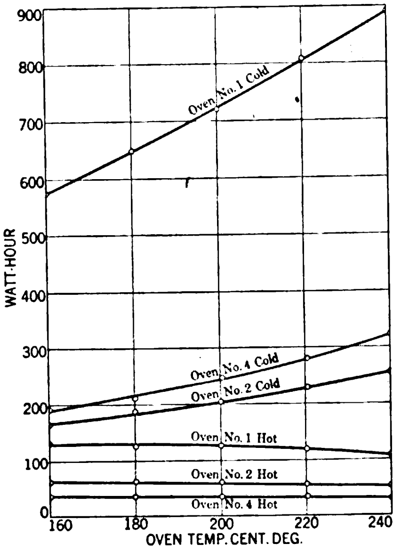

FIG. 19—ENERGY REQUIRED TO BAKE BISCUITS STARTING WITH OVEN COLD AND WITH OVEN HOT

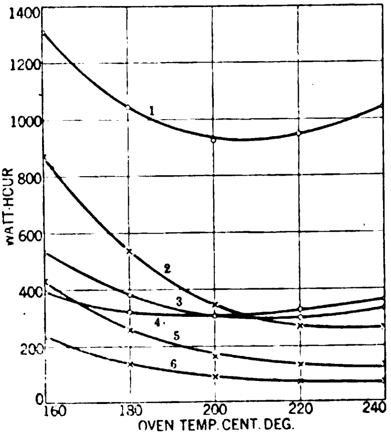

FIG. 20—ENERGY REQUIRED TO BAKE BREAD STARTING WITH OVEN HOT AND WITH OVEN COLD

1. oven No. 1 cold 4. oven No. 4 cold
2. " " 1 hot 5. " " 2 hot
3. " " 2 cold 6. " " 4 "

Biscuit samples were also baked in ovens No. 2, 3, and 4. In oven No 2 the biscuits did not brown satisfactorily on top as there was no heating element in the top of the oven. Oven No. 3 was found to be unsatisfactory for baking biscuits because with the heating arrangement used it was difficult to get high enough temperatures. The biscuits baked in oven No. 4 were satisfactory. The time of baking and the per cent loss of weight checked with the values obtained for oven No. 1.

The curves of Fig. 20 give the energy used in baking bread at the various oven temperatures with and without preheating. It will be noticed that for all the ovens the energy required is a minimum above 220 deg. The most economical temperature for baking bread when the oven is already heated is therefore from 220 to 240 deg. cent.

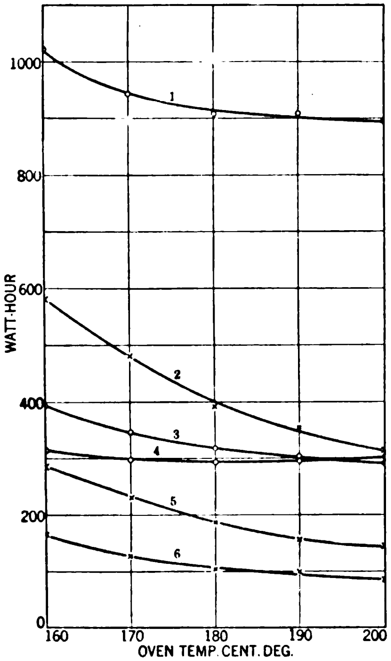

FIG. 21—ENERGY REQUIRED TO BAKE SPONGE CAKE STARTING WITH OVEN HOT AND WITH OVEN COLD

1. oven No. 1 cold 4. oven No. 4 cold
2. " " 1 hot 5. " " 2 hot
3. " " 2 cold 6. " " 4 hot

The temperature for which the energy required is a minimum lies between 200 and 215 deg. cent. depending on the oven used. Although the insulation of oven No. 4 is very much better than oven No. 2, it will be noticed that above 205 deg. oven No. 4 requires more energy for baking bread than oven No. 2. This is due to the larger amount of energy required for the preheating.

The curves of Fig. 21 give the energy used in baking sponge cake at the various temperatures with and without preheating. As shown by the curves the most economical temperature for baking sponge cake, when the oven is already heated, is 200 deg. cent. Except for oven No. 4 this is also the most economical temperature when the oven is started at room temperature. For oven No. 4 the most economical temperature is 180 deg. but the difference in the energy required at 180 and 200 deg. is slight. Because of the poorer quality obtained at 200 deg., the best temperature for baking sponge cake will be between 180 and 190 deg. cent.

Consideration of the baking curves as a whole will emphasize the importance of the preheating characteristics in designing an efficient electric oven. For the kind of baking which requires a high temperature for a short time the preheating loss is considerably greater than the radiation and convection loss. Unless some method can be found for decreasing the energy used in heating the oven up from room temperature, it will not be practical to greatly increase the heat insulation of the ovens used for domestic baking. This does not apply, however, to ovens which are used for long intervals at the same temperature.

CONCLUSIONS

Much has been accomplished recently by domestic scientists in substituting accurate scientific methods of cooking for the vague and indefinite rules of our grandparents. Especially is this true in the field of candy making. There is, however, an enormous amount of work yet to be done before an inexperienced person can hope to get uniformly good results without first experiencing many failures and wasting much good material.

With reference to the use of a thermometer for the standardization of oven temperatures Miss M. B. Van Arsdale, assistant professor of household arts at Columbia University, says:

> Regarding the inexperienced housewife, it can truly be said that with an accurate thermometer her results would undoubtedly be more uniformly good—and we believe that the receipe books of the future should not read merely " bake until done in a moderate oven " or " according to judgment," but will also state how long and at what temperature, so that in the hands of even the inexperienced these recipes will yield not occasionally good but uniformly good results without the discouragement of many failures, the sacrifice of much time and the waste of much good material. Thus the scientific treatment of the subject added to our traditional knowledge should tend to evolve an even higher type of cookery than we have had in the past.

The present status of the science of cookery is due, in a large degree to the lack of adequate means of controlling the temperature of the food. When using the ordinary wood or coal cooking range the degree of heat is controlled chiefly by dealing with the food itself rather than by regulating the heat at the point of combustion. The amount of draft necessary to promote the combustion of the fuel causes too great a degree of heat in the oven or on the stove to enable the cook to deal with the food in the proper way except by constantly watching it, stirring it, and changing the position of the vessel on the stove or in the oven.

With the advent of electric ovens a revolution in the methods of cooking has become possible. Automatic electric ovens will probably be developed in which the temperature will be accurately controlled and the necessity of constant vigilance will be removed. Some kinds of food will even be prepared in advance, placed in the oven, and without any further attention on the part of the housewife the current will automatically be turned on at a predetermined time. The temperature of the oven will increase to the desired value and there remain constant until the food is properly cooked.

With this method perfected the advantages of electric cooking over the other methods will be great and in many cases the cost will not be excessive. To the possibility of obtaining uniformly well cooked food should be added the saving to the housewife in time and worry, and the absence from the kitchen of excessive heat.

The present day problem in electric cooking is to determine the methods of cooking that will yield the most in nutrition and flavor, and to formulate definite rules or directions so that a particular article of food can be cooked in the best possible manner by persons of ordinary skill. The engineer's problem is then to design practical cooking devices in which the temperature can be accurately regulated with a minimum of attention on the part of the housewife.

Electric cooking may be classified according to the temperature to be used in the oven. The baking of bread, cake, and pastry requires a high oven temperature from 170 to 240 deg. cent. In the average family where the oven is used intermittently a large part of the electricity used in this class of baking will go to heat up the oven from room temperature to the required baking temperature. In other words the preheating loss will be large compared with the radiation and convection loss.

The preparation of vegetables, cereals, and meats (except for searing, broiling, and frying) requires a low degree of heat, 80 to 120 deg. cent., applied for several hours. In this class of cooking the preheating loss is small in proportion to the radiation and convection loss.

The increased popularity of the fireless cooker indicates that people are learning that food can be cooked at temperatures lower than the boiling point of water. The particular temperature of 100 deg. cent. has long been the one used for cooking cereals, vegetables and meats, because it is the easiest temperature to maintain at a constant value and not necessarily because it gives the best possible results. The fact that several hours are required for the cooking is not a disadvantage when the process is automatic and does not require the attention of the housewife. Aside from the question of the quality of the food and the saving in electricity, four hours would probably be the best time to cook the food. The housewife could put in the food for the midday meal immediately after breakfast while the oven was still hot. When it is taken out she could put in the evening meal so that the oven would be used continuously. The preheating loss would thus be reduced to a minimum. During the latter part of the afternoon the housewife need not be tied to her kitchen, as all that would be necessary at this time would be to dish up the food and serve it.

The electric light and power companies should be interested in perfecting this method of cooking and in bringing it to the attention of their customers. A combination of the electric oven and the popular fireless cooker would be a very desirable load for the central station. It would be a nearly steady all day load and would not interfere with the peak load even in the winter as sufficient heat can be stored in a well insulated oven to keep the food hot enough to serve for an hour or more after the current is turned off.

Since the experiments of the author are very meager in comparison with the enormous amount of investigation which will be necessary before the art of cookery will be reduced to a science, it is thought that the results obtained will serve more as a preliminary to further investigation than as a basis for immediate reforms in the methods of electric cooking. Even though the complete data were at hand for inaugurating such a revolutionary reform in the methods of cooking, the inertia of the present methods would be considerable so that the introduction of definite rules of time and temperature would take a long time.

In cookery as in photography the time and temperature methods will benefit the amateur to a greater extent than the professional, who because of his years of experience and many failures in the learning will be able to get uniformly good results with the less definite methods. Hence the greatest field for an automatic electric oven will probably be in the middle class home where the cooking is done by the housewife rather than by servants.

SUMMARY

1. The energy lost when the door of an electric oven was opened for 15 seconds was found to vary from 5 to 15 watt-hr. depending upon the temperature of the oven.

2. The time required for roasting a rolled rib roast of beef rare, medium rare, and well done was determined for various oven temperatures, the shortest time of roasting being at 160 deg. cent.

3. The per cent loss of weight of the roasts was found to increase with the oven temperature used.

4. The most economical temperature for preparing rare and medium rare roasts was found to be 100 deg. in each oven. For well done roasts 120 deg. cent. is the most economical temperature.

5. With electricity at $.05 per kw-hr. it is at least $.02 cheaper to roast beef at 100 to 120 deg. cent. than at 180 deg.

6. It was found that at least 1000 watt-hr. could be saved by searing the roast on top of the stove instead of heating the whole oven up to 250 deg. cent.

7. A method was devised for determining the most economical temperature for baking bread, cake, and biscuits. The minimum time for baking and the per cent loss of weight were determined for several oven temperatures.

8. The range of oven temperatures for baking biscuits was found to be from 200 to 240 deg. cent. Starting with the oven at the required temperature, the energy used in baking biscuits is practically the same for all oven temperatures. If it is necessary to heat up the oven from room temperature, the most economical oven temperature is the lowest which will give satisfactory results; *i.e.*, about 200 deg. cent.

9. The range of oven temperatures for baking a small size loaf of bread was found to lie between 180 and 240 deg. cent. Starting with the oven at the required temperature, the most economical temperature for baking bread is between 220 and 240 deg. cent. When preheating is included, the most economical temperature for a small size loaf was found to be between 200 and 215 deg. cent.

10. The range of oven temperatures for baking sponge cake was found to lie between 170 and 190 deg. cent. For baking sponge cake the most economical oven temperature is the highest temperature which will give satisfactory results; *i.e.* about 190 deg. cent.

11. The results of the cooking experiments in electric ovens indicate that it is possible to reduce the art of cooking with electricity to an exact science. If definite rules of time and temperature were formulated for cooking each article of food,

the inexperienced housewife could obtain uniformly good results with the expenditure of a minimum amount of attention and fuel.

The author begs to acknowledge his indebtedness to Misses Stanley, Daniels, and Troxell of the home economics department of the University of Missouri for their many valuable suggestions and for their kind supervision of the bread, cake, and biscuit experiments, and to Messrs. Atkins, Brinkmeir, Crider, and Macom for their assistance in taking readings.

American Institute of Electrical Engineers

PROVISIONAL SPECIFICATION FOR INSULATOR TESTING

COVERING INSPECTION AND TESTS OF HIGH-TENSION LINE INSULATORS OF PORCELAIN, FOR OVER 25,000 VOLTS*

The present provisional specification was approved and recommended by the Power Transmission Committee of the American Institute of Electrical Engineers, Feb. 1915.

SPECIFICATION

Introductory:

This specification covers certain methods of test and inspection which have been found well suited for testing high-tension line insulators for use under the ordinary conditions of power transmission work. It is expected to serve as a skeleton or model specification and may be supplemented by such additional provisions as may be appropriate for any particular case.

Certain portions of the specification are added as a guide where designs are to be offered by several bidders for competitive tests. In such a case bidders will understand from the specification all the requirements they must ultimately meet if their bids be accepted.

GENERAL SPECIFICATION COVERING ALL TYPES OF INSULATORS

1. (a) This specification is intended to cover the checking of the design and the testing and the inspection of the factory output, of..................................porcelain insulators, cat. No.................... of.......................................Company; to be manufactured for the ....Company.

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*Copies of this specification may be had at a cost of 25 cents by application to the Secretary of the A. I. E. E., 33 West 39th Street, New York City.

(b) The operating voltage is..................................and the frequency is..............................

c. Definitions: By " insulator " is meant the complete insulator or group of insulating members including all the parts necessary to support the conductor from the crossarm or on the pin as the case may be.

By " unit " or " unit insulator " is meant a suspension insulator element complete, having a metal cap and pin.

By " shell " is meant a single porcelain piece without cement or cap or pin.

2. *Drawings:*

A dimensioned drawing shall be furnished showing the complete insulator and metal parts, or, if the insulators are built up or composed of a string of units, showing the details of a unit and all the clearances between units and metal parts.

3. *Inspection:*

The maker will give to the purchaser or his representative such access to his works at all times during working hours as is reasonable and necessary to determine the suitability of material to be supplied, and shall furnish all necessary apparatus, labor, and other facilities for making the tests herein called for without cost to the purchaser. All good insulator units destroyed in the tests here called for are to be paid for by the purchaser at the contract price.

All insulators are subject to final inspection, test and acceptance at maker's factory.

Neither the inspection nor waiving of inspection nor the purchaser's acceptance will relieve the maker from obligation to furnish material in accordance with this specification.

4. *Design:*

All insulators shall be designed as far as may be practicable to fail by flash-over and not by puncture under excess voltage tests, especially under impact tests.

Insulators shall be of robust construction and design so as not to be easily injured in handling.

Explanatory Note:

The ultimate criterion of the merit of an insulator is its performance in service and the best available measure thereof is its behavior under definite tests. However, as no practicable tests actually reproduce service conditions, for example in the matter of high-frequency voltage or deposits of dust, criticism on theoretical grounds is valuable, and, other things being equal, preference should be given to the insulators most closely conforming to theoretically best designs.

Altitude:

Careful attention in specifying flash-over voltages should be given to the fact that for varying altitudes the breakdown strength of air varies approximately though not exactly as the barometric pressure.

METAL PARTS

5. *Corrosion:*

All metal parts shall be of non-corrodible material or shall be galvanized or sherardized in accordance with the specifications for galvanizing prescribed by the joint committee of the National Electric Light Association in its Specification for Overhead Crossings of Power Lines Above Telephone and Other Low-Voltage Lines. Surfaces shall be free from roughness or projecting points; bearing surfaces shall be smooth enough not to injure cables.

6. *Factor of Safety:*

Metal parts shall have a factor of safety of at least three over the maximum stress that they receive in service, except that with pins for pin type insulators the factor may be reduced to two where a higher factor is impracticable. The maximum service strain is here agreed upon as————lb.

PORCELAIN

7. *Quality:*

All porcelain shall be dense and homogeneous as is best adapted to high-tension insulator requirements, free from injurious cracks, blisters and flaws or other defects that would render them unfit for use in insulators. The burning of all porcelain sections shall be done so as to insure even vitrification but shall not render the porcelain unduly brittle. The surface shall be smooth and uniform and the body of the porcelain shall be moisture-proof.

8. *Glazing:*

The glazing shall be of..................color and of a reasonably uniform shade, smooth, hard and continuous over all surfaces except those to be in contact with the cement. It shall be unaffected by weather, ozone, nitric acid, nitric oxides, alkali dust, or sudden changes in temperature over the atmosphere range.

9. *Absorption: Explanatory note.*

While imperviousness of the porcelain to moisture is of supreme importance, no satisfactory test of this quality is known.

CEMENT

10. *Assembling:*

All cemented joints between insulator parts shall be carefully made, using for this purpose the best grade of neat Portland cement, thoroughly mixed, and plentifully supplied with moisture during setting. The assembly shall be so done that no hollows or voids will be left between the cemented surfaces. All superfluous cement must be cleaned off of the insulator before crating.

ELECTRICAL TESTING

Note. Sections 11 to 15 inclusive are particularly applicable to competitive tests and to tests the results of which are to be compared to similar tests made with other testing apparatus. In cases where merely a comparative study of different designs of the same make is to be made, all tests being carried out on the same testing apparatus, it is usually satisfactory to use the standard test apparatus of a first-class maker.

It should be definitely stated in the contract whether sections 11–15, inclusive, are to be adhered to or not.

11. *Wave Form:*

The wave form of the generator shall be a true sine curve within the limits specified for generators by the Standardization Rules of the American Institute of Electrical Engineers and may be checked by the methods therein prescribed.

12. *Control of Voltage:*

The voltage shall be controlled in such a way as not to distort the wave form.

One satisfactory method of control is the use of a regulator consisting of a shunt resistance connected directly across the low-voltage side of the transformer, and a series resistance in the supply. The shunt resistance must always bypass at least five (5) times the exciting current of the transformer. The principal control is effected by the series resistance. This method is often spoken of as the potentiometer method.

13. *Measurement of Voltage:*

The method of measuring the voltage on the test circuit shall be that method recommended by the American Institute of Electrical Engineers, covering such cases.

14. *Kilowatt-Ampere Capacity of Testing Apparatus:*

The kilovolt-ampere capacity of the testing apparatus, including any series resistance used, is important, for the leading current taken by the insulators tends to alter the voltage of the test apparatus. The maximum current taken from the test apparatus shall not be so great as to distort the voltage wave more than permitted for generator electromotive force waves by the A.I.E.E. Standardization Rules.

15. *Surrounding Conditions During Tests:*

In *design checking* tests of insulators having an operating voltage not exceeding 75,000 volts, no object other than leads and supports should approach nearer than 6 ft. (1.8 m.) to the insulator. For insulators having a higher operating voltage, the conditions for the "design test" of complete insulators should be made as nearly as practicable the same as the conditions of actual service as regards the grounding of one side of the insulator and the arrangement and distance of grounded objects in the neighborhood. A conductor of 6 ft. (1.8 m.) or more in length, extending equally on both sides of the clamp, should be used to represent the transmission wire.

NOTE—In these tests the walls of the room will ordinarily introduce a very serious departure from the conditions of outdoor service. Open-air tests where feasible are preferable from this point of view.

Routine tests, not being on complete insulators or insulator strings, do not require these precautions.

16. *Frequency:*

Tests should be made at the frequency at which the insulator is to be used. Where special agreement is made tests may be made at 60 cycles on insulators intended for use on higher and lower frequencies. No error of a serious magnitude will be expected within the range of 25 to 133 cycles.

17. *What Constitutes a Breakdown or a Flash-over:*

An insulator is said to "fail" or "break down" under a voltage test whenever a puncture occurs in any part of the insulator. It is said to flash over when a discharge of any sort passes all the way from one terminal to the other, since such a discharge would be followed by an arc on a power line.

Local breakdown, either corona or local sparks, while an important symptom, indicating severe local stress, does not constitute a flash-over. The weight to be given to such local breakdown, however, is a matter of judgment.

18. *Rain Tests:*

Water should be sprayed on the insulator at a uniform rate averaging 1 in. (2.5 cm.) depth in 5 minutes, and should be reasonably uniformly distributed over the whole insulator. The rate of precipitation shall be measured by collection of water in a pan at the location of the insulator, the insulator being removed. A fairly satisfactory spray in the form of a fine mist can be obtained by some forms of spray nozzles where pressure is available.

The spray shall strike the insulator at an angle of approximately 45 deg. with the vertical.

The water used shall have a high specific resistance, not less than 5000 ohms per cu. in. (12,700 ohms per cu. cm.). Pure water may often be obtained from condensed steam or melted ice, preferably artificial ice, or rain. Municipal water supplies are often so impure as to seriously impair the performance of the insulator on the wet flash-over.

When insulators are to be used in localities subjected to salt spray or alkali or acid mists, or to conditions producing dew deposits, special tests may be agreed upon.

19. *Puncture Under Oil:*

Tests on a certain percentage of insulator units, ordinarily not exceeding ¼ of one per cent, should be made to determine the ability of the insulator to resist puncture and to measure the uniformity of the product. This test is best made by submerging the insulator in oil.

For this test each suspension insulator unit should be completely assembled with its standard metal parts.

With pin type insulators there should be attached to the head of the insulator wires representing the tie and line wires, and a metal pin should be placed in proper manner in the pin hole.

The test voltage should then be applied to the metal parts in each case. The puncture value obtained under these conditions should not be less than 150 per cent of the dry flash-over voltage and should where possible be much higher. In the case of suspension units a factor approaching 200 per cent has sometimes been obtained.

The puncture voltage that must be met in the actual tests (§25) should be here specified for each contract, viz., ... volts.

In making the test, apply to the insulator a voltage 30 to 40 per cent below the dry flash-over value and then raise the voltage gradually or by steps, until puncture occurs, at a rate of about 10,000 volts per second. The puncture value of porcelain is very sensitive to the length of time voltage near the maximum is applied; the puncture voltage may be lowered as much as 20 per cent by long-continued application of the test voltage.

20. *Series Spark Gap:*

In routine testing, it is well to have a short air gap between each insulator under test and the testing line, that the character of the charging current may be judged by the appearance of the arc.

PIN TYPE INSULATORS

21. *Inspection:*

All parts shall be inspected before assembling.

22. *Routine Tests. Electrical Tests Before Assembling:*

All insulator shells, before being assembled, shall be tested for three minutes at the voltages given in the following table. Should any shell be punctured in the last minute of test, the test will then be continued, after the removal of the punctured piece, until no puncture occurs in one full minute of test. These tests are to be conducted by inverting the parts in pans of water and placing water inside the several pieces, the potential then being applied to the two bodies of water.

Note. The water both inside and outside shall be filled to within one quarter of an inch of the highest point to which the later applied conducting parts, including cement, will extend.

The individual tests in the various shells shall be as follows:

Head.........................,	volts
Second Shell....................,	“
Third Shell....................,	“
Fourth Shell....................,	“
Center........................	“

23. *Routine Tests—Final Electrical Test:*

All completed insulators shall be tested according to one or the other of the four following tests. One of these tests should be definitely specified for each lot of insulators tested under these specifications.

a. The insulators in groups shall be subjected to a voltage steadily applied just below the flash-over voltage for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some insulator of the set occasionally, but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all insulators for one alternation.

If an insulator of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The insulators in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flash overs exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential without removing the voltage. In this case the time of the second part of the test should be reduced to one minute.

d. This test is the same as test (b) above except that instead of applying this testing to insulators in groups, the insulators shall be tested singly and the voltage continued for a period of 20 seconds.

Note. In all the tests (a), (b), (c) and (d), above, it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

24. *Design Test—Mechanical:*

The following design test shall be made on enough complete insulators, usually not exceeding $\frac{1}{4}$ of one per cent, to determine the behavior of the design and the uniformity of the product.

The insulators shall be capable of withstanding for 15 seconds without signs of distress a pull of.................... lb. (.................... kg.) applied at the tie-wire groove in a direction at 90 deg. with the axis of the insulator and pin. For the purpose of making this test, the insulator shall be mounted on the pin to be used in service. In case of failure the question as to whether the insulator or the pin is at fault shall be determined by testing again with a solid steel pin turned from a piece of round steel of such dimensions that this piece of steel acting as a pin for the insulator will not bend under the above-mentioned load.

It is desirable that a number of insulators be tested to destruction to show approximately the margin in mechanical strength.

25. *Design Tests—Electrical:*

The following design tests shall be made on enough complete insulators to determine the performance of the type. The insulator shall stand without failure:

(a) A test for *flash-over, dry*, of three times the potential between line wires, applied for one minute.

(b) A test for *flash-over, wet*, of not less than 2 times the potential between line wires, applied for one minute.

(c) Puncture test under oil shall be made as specified under §19 above.

SUSPENSION TYPE INSULATORS

26. *Routine Tests—Electrical Test Before Assembling:*

All insulator shells shall be tested according to one or the other of the three following tests. One of these tests should be definitely specified, for each lot of shells tested under this specification.

a. The shells in groups shall be subjected to a voltage steadily applied just below the flash-over test for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some shell of the set occasionally but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all insulators for one alternation.

If a shell of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The shells in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flashes exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The shells in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case the time of the second part of the test should be reduced to one minute.

NOTE 1. In all the tests (a), (b) and (c), above, it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the shells during the continuance of the power arc.

NOTE 2. In making these tests the insulator shells are to be inverted in a pan of water and water placed in the inside. The water both inside and outside shall be filled to within one quarter of an inch of the highest point to which the later-applied conducting parts, including cement, will extend.

27. *Routine Test—Mechanical Test:*

After at least ten days setting of the cement, all units shall withstand for 3 seconds without signs of distress a mechanical pull of .... lb. (................ kg.), in line with the axis of the insulator. Insulators may be given this test after a shorter period of setting, at the risk of the maker.

28. *Routine Test—Final Electrical Test:*

All completed insulator units shall be tested according to one or the other of the four following tests. One of these tests should be definitely specified for each lot of insulators tested under this specification.

a. The insulator units in groups shall be subjected to a voltage steadily applied just below the flash-over test for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some unit of the set occasionally but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all units for one alternation.

If a unit of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The insulator units in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flashes exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case the time of the second part of the test should be decreased to one minute.

d. This test is the same as test (b) above, except that instead of applying this testing to units in groups, the units shall be tested singly and the voltage discharges continued for a period of 20 seconds.

NOTE. In all the tests (a), (b), (c) and (d) above it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

This test shall be made after the mechanical test above prescribed, §27.

29. *Design Tests—Electrical:*

The following design tests shall be made on enough complete assembled insulators, not exceeding ¼ of one per cent, to determine the performance of the type.

(a) A test for *flash-over*, *dry*, of one insulator unit having its normal position in the string and of a complete insulator string consisting of .... units, of .... volts, and.......... volts respectively, applied for one minute.

(b) A test for *flash-over*, *wet*, of a single insulator and of the string, of...... volts and...... volts respectively, applied for one minute.

(c) The puncture test under oil shall be made as specified under §19 above.

It is preferable that the arc-over of the complete insulator when the test voltage is sufficiently raised shall be over the insulator as a whole and shall not be over the individual elements.

30. *Design Tests—Mechanical:*

The following design test shall be made on enough complete insulators, usually not exceeding ¼ of one per cent, to determine the behavior of the design and the uniformity of the product.

After at least two weeks setting of the cement, the insulators to be tested shall withstand for 15 seconds without signs of distress a pull of .... lb. (................ kg.) in line with the axis of the insulator.

It is desirable that a number of these insulators be pulled to destruction to show approximately the margin in mechanical strength.

APPENDIX

The following tests are recommended as desirable where appropriate. They are not incorporated in the above specifications as experience with them is not yet sufficiently broad.

31. *Uniformity Puncture Test:*

Twenty-two single insulators, chosen at random from stock, which have passed all routine tests, shall each in turn be punctured under oil as provided for oil tests in §19 above. Any twenty of these values of puncture voltage shall then be selected by the maker. The difference between the maximum and minimum of these twenty puncture voltages must not be more than 20 per cent of the average voltage. This test should be repeated with one or more additional groups of 22 disks, not exceeding in the aggregate $\frac{1}{4}$ of one per cent of the total, enough to determine the uniformity of the product. In case of failure of the lot to pass this test, the other insulators from the same burnings shall be tested as specified under §28, but for a period 5 times that there specified.

32. *Design Test—Impulse Test:**

Some form of impact or high frequency test is of the greatest importance in testing high voltage insulators, at least for the design tests. Two or three forms of such tests have been proposed, and it is expected that a supplement to this specification will be issued when these tests have been sufficiently standardized.

33. *Design Test—Combined Mechanical and Electrical Test:*

The following design test should be made upon enough insulators to determine the performance of the design and the uniformity of the product.

An insulator placed in an insulated testing machine and impressed with a voltage just under or just over the flash-over voltage (as may be agreed upon), shall be subjected to a gradually increasing mechanical pull until puncture occurs.

The insulator should not puncture at less than twice, or, preferably, three times the maximum pull to which the insulator is to be subjected in service, as fixed in §6 above.

34. *Uniformity—Brittleness Test, Applicable Especially to Suspension Insulators:*

The following uniformity test should be made upon enough insulator units to determine the performance of the design and the uniformity of the product.

A completed insulator unit which has passed all routine tests shall be placed in ice water and the temperature of the water raised to boiling. The heating should not begin until after the insulator has been in ice water 60 minutes to permit all parts to come to the same temperatures. The water should then be heated at a uniform rate of about one degree cent. per minute. After remaining at boiling temperature for 30 minutes the unit may be removed and should afterward be tested either by the measurement of its insulation resistance, using one or two thousand volts for the measurements, or by the standard routine electrical test (§28), or both.

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*For an example of the application of such a test see paper by Imlay and Thomas, TRANS. A. I. E. E. Vol. XXXI, 1912, p. 2121.

35. *Percentage of Failure in Routine Tests.* The percentage of punctures in the electrical tests is a rough measure of the burning of the porcelain and the care in manufacture. A relatively large percentage of failures, perhaps over 5 per cent, suggests under-firing. It is recommended that the following modification be applied to routine tests §23 and §28:

"When the percentage of punctures in any group of insulator units or shells under test simultaneously, exceeds 5 per cent, the length of the time of application of the test voltage shall be doubled for that group".

DISCUSSION ON "SUBMARINE SIGNALING" (BLAKE), PHILADELPHIA, PA., OCTOBER 12, 1914. (SEE PROCEEDINGS FOR OCTOBER, 1914.)

(*Subject to final revision for the Transactions.*)

W. S. Franklin: When you lower that oscillator into the water, the two diaphragms are working in like phases, are they not?

H. J. W. Fay: Yes. That means that the water on one side is being compressed.

W. S. Franklin: Don't you cover one of those diaphragms completely, and only expose one to the water?

H. J. W. Fay: This diagram doesn't show the water-tight oscillator as it should. This is a form of scillator that was put inside the ship, not put in the water. A water-tight oscillator has a ring around the base of the pole piece, and the third diaphragm is mounted on that ring, and this rod excites that diaphragm.

W. S. Franklin: If I may explain just what I have in mind—you say that your wave length there would be something like thirty or forty feet. Now we speak of each side of that apparatus as being a center from which waves go out—

H. J. W. Fay: No, only one side.

W. S. Franklin: That is what I wanted to know. Only one side is covered?

H. J. W. Fay: Yes.

Elmer A. Sperry: This seems to me a most ingenious apparatus. Think of the diaphragm that you and I use when we speak into a telephone, a small affair that is about as thick as paper, and then consider the diaphragm that this apparatus works—three-quarters of an inch thick and 24 inches in diameter; and it takes that size of diaphragm to be in tune with the 1000 beats or 500 full oscillations per second to which this instrument is tuned with the alternating current of this frequency. I understand that when this was tried on the *Delaware* it was heard distinctly on the upper deck in a very remote position from where the apparatus was installed. But the most remarkable thing to me is that it can be again used as a receiver. The 8 by 8-in. copper tube, only $\frac{1}{8}$ in. thick, seems a very simple factor to set up a reaction back into the alternating winding, giving evidence of remote sound, especially when in attune with this diaphragm.

G. A. Hoadley: The paper speaks of the most important use of this apparatus on submarines, for submarine signaling from one vessel to another. Has there been any method devised by means of which submarines not belonging to our party can be prevented from receiving the message?

H. J. W. Fay: No, not yet. At a mile's distance, the sound is so loud that it can be heard all over the submarine boat without any receiving apparatus. The point that you mention has been in mind, but it could not be done with vibrations such as are used now. It would be possible with vibrations that are below the range of audibility.

H. A. Hornor: Have any experiments been made upon interference of two signals at a time? Wouldn't that be a cause of confusion of the signals?

H. J. W. Fay: Yes, probably, unless they were widely different in tune. Then the oscillator at 500 might not pick up the oscillator that was tuned to 1000. We have simply worked the oscillator out for that one pitch at the present time, and the greatest number that we have known to be used at any one time has been two. We have not had a third oscillator in any of the tests to break in on the signals.

W. S. Franklin: Professor Webster of Clark University has been working quantitatively on a problem which involves making among other things, an accurate measurement of the number of watts that are given out as sound by ordinary tuning forks, with and without resonance. Have you any idea as to the actual watts output represented by the sound that is produced? I don't mean watts entering into the receiver, but watts of energy in the sound.

H. J. W. Fay: The nearest I can tell you is that last Saturday we made a test with one oscillator 46 ft. from the other and measured the amount of current received in the alternating winding of the receiving oscillator, and we got 0.025 ampere. The input was 13 amperes at 170 volts on the alternating current and 7½ amperes at 110 volts on the direct.

George Breed: As I understand the description, the armature oscillates in a direction longitudinal with the bolt. Then, presumably, it must be centered in some way and held clear and free between the magnet poles, and furthermore, if it be free to oscillate, its supports cannot be absolutely rigid.

It would be interesting to know how the armature is held in place, and how much elasticity there is in its supports. I suppose the oscillating system thus formed is so proportioned with respect to mass and elasticity, that its nautral frequency of oscillation is about 500 per second.

H. J. W. Fay: The amplitude of movement is 0.01 in. The small diaphragms on the rod support the copper tube.

W. S. Franklin: If the amplitude of this apparatus is known, Professor Webster's formula will enable the actual watts of sound output to be calculated with a very high degree of accuracy.

John B. Taylor (by letter): Before commenting in detail on the paper by Mr. Blake, a few very general (and perhaps obvious) remarks may be in order.

Communications between individuals more or less widely separated may be accomplished only by transfer of matter or energy from one to the other. Exchange of intelligence by moving material things has culminated in the typewritten letter.

The spoken word and the sign exemplify communication through forms of energy. Here one involves mechanical, the other radiant energy. In the business of travel and transportation by land, as well as by sea, both audible and visible signals are extensively employed, one supplementing the other. Light signals serve fairly well in disclosing location or direction through "straight-line" propagation of the radiant energy and the working characteristics of the receiving instrument, the eye. Non-transparent objects cast shadows, *i.e.*, the radiation does not bend around obstacles, hence rain, snow and especially fog disturb, or prevent entirely, dependence on visual signals. Layers of air of different optical properties may also give rise to mirages or other aberrations.

Sound signals do not readily disclose location or direction. Sharp sound shadows are not noticed with wave lengths of the pitches commonly employed, and the ears are not well adapted nor trained to locate sources of sound with assurance or accuracy. Further difficulties arise on account of reflections from objects giving echoes or interferences which may be misleading, while other sounds and noises, necessary and unnecessary, reduce the sensibility of the ear to feeble sound and distract the attention from the particular sound signal.

The paper under discussion describes a system of marine sound signaling using the water of ocean, river or lake rather than the air as transmitting medium. To do this, more complicated sounding and receiving equipment is needed. Doubtless the water will usually be more homogeneous acoustically than the air. The inhabitants of the water are assumed to be comparatively quiet. There are, however, extraneous sounds which give trouble. Is it right to infer that these are greater than undesired sounds in the air, since no mention of this point is made in the list of five advantages of water over air? (page 1571).

The descriptions of the determination of depth and of iceberg distance by echo and reflection naturally lead one to question the reliability of direction location in the presence of other ships, icebergs, rockledges, reefs, islands, not to mention shore and bottom.

The greater speed of transmission through water (approximately 4 times) is an advantage from a telegraphic standpoint where sound signaling through air would leave the hearer a full minute behind the sender in 11 or 12 miles. In fact, the 15-sec. interval for water signaling for the same distance may make much confusion. The greater velocity is a disadvantage in depth and distance determinations.

The remarks of the author (page 1574) on compressibility of water and large forces and strength of materials needed to make a sound in water are incomplete without data on the number of kilowatts expended and the excursion of the copper tube with its attachments and diaphragm. A steel rod will readily transmit the sound of a pin scratching or a watch ticking, though the velocity of sound in steel is about 14 times that in air and though steel is much heavier than water, thus indicating far greater rigidity or incompressibility than water.

What is the basis of the author's statement that a telegraphic "dot" must persist ten cycles for its pitch to be recognized? Lord Rayleigh ("Theory of Sound," Vol. II, page 452) cites tests to show that *three* consecutive vibrations determine pitch with considerable accuracy. Tests of Mr. Arthur Farwell (M. I. T. thesis, 1893, I believe unpublished) using a different method—a telephone receiver—corroborate the figure.

Submarine signaling by the "telegraphic oscillator" may well supplement other signal methods, as none are complete and at all times dependable. Sound signals through air must be retained for the benefit of small craft that cannot have submarine devices. Though a given sound may not always be heard at the same distance, the air is the natural medium for men. The ear, while sensitive to feeble sounds, may be aided, and an increased range may be obtained by the help of apparatus. Probably many cases of alleged erratic transmission of sound are due to mistakes in judging direction. To determine better the direction of the source of sound, an interference device or apparatus indicating phase of sound at two slightly separated points determines the direction from which the sound wave arrives (see U. S. patent No. 939,349).

G. A. Hoadley: One question in connection with this paper is the necessity of a high degree of energy in sending out the sound. A pin scratch on a wire fence can be heard at a long distance, not because the steel or iron wire used is so little compressible, but because of its high elasticity, and it seems to me that in the case of submarine signaling it is a question of higher elasticity of the medium rather than the amount of the compression that is to be used. I am questioning whether it would be possible in any way to apply less energy and still set up the wave motion.

J. L. Woodbridge: How accurately can the direction from which the sound proceeds be determined by the receiving vessel?

H. J. W. Fay: Within a point on the compass, or 11¼ deg., at distances of between two and three miles.

W. S. Franklin: The accuracy of locating directions of sound must depend on the distance apart of the two points at which the sound is received. How far apart are the two receivers when you attempt to locate directions of sound—ten feet—or so?

H. J. W. Fay: The distance between the two sides of the bow of a ship—more than ten feet.

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